Documentos de trabajo* Número I – 2021

# Industrialization and human resources training: an approach of policies coordination

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enero de 2021

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# Industrialization and human resources training: an approach of policies coordination.

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**Abstract** This paper proposes a dynamic model to show that the coordination of public policies is a key driving factor for an economy to develop successfully. We analyze three public policy domains: innovation policies; policies of human resources training, wages and employment; and push policies. These policies determine whether the economy achieves paths that drive it to a full industrialization, which happens when the initial state lies above the industrialization frontier. Otherwise, the economy would remain stuck in a poverty trap, where there are no marginal incentives for industrialization or training of labor.

**Keywords** Industrialization Policy · Coordination · Technological Change · Choice of Technology · Push Strategies · Evolutionary Dynamics

**JEL classification** C73 · I28 · J24 · O25 · O38

## 1 Introduction

This papers presents a dynamic model in a closed economy, where the coordination of public policies is a key driving factor for development. Our concern is which economic dynamics allows some countries -but no others- to successfully

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scape from a poverty trap, reaching a high development, and how a government intervention can accelerate this process. We analyze three domains of public policies and their coordination: innovation policies; policies of human resources training, wages and employment; and push policies.

From an evolutionary perspective (see Dosi and Nelson [18]), an industrialization process is the result of a combination of factors, such as industrial structure, competence and technology. This has been observed in cases at which some economic sector achieves national leadership; Mowery and Nelson [29] propose that these factors should not be analyzed individually. Therefore, we highlight the role of the coordinating agencies within industrializing processes to coordinate policies, incentives and simultaneous investments, and to ensure that a fast growth is carried out with good articulation, as it has descriptively claimed by many authors (see, for example, Krugman [26]; Basu [8]; and Allen [5]).

We focus on industrial policy, which is referred as the strategic effort by the state (in coordination or not with the private initiative), to promote the technological development and growth of one or several sectors of the economy. This effort attempts to alter the structure of production of an economy toward better prospects for economic development. Cimoli et al. ([13]) mention within industrial policy: education and training policy, science policy, creation of national champions, state owned firms, price regulations, tariffs, governance of labor markets, etc.

**We build a multisectorial market economy model with representative agents: one representative firm for each sector and a representative consumer for the whole economy. The production and consumption decisions are the result of profit/utility maximization and prices that ensure market clearance and only involve one production factor: labor. However, we consider that the technology selection by firms and the qualification decision by workers follow a replicator dynamic process. This allows us to analyze the technology transition dynamics and how public policies may affect them.**

**Finally, we assume that the cost involved in modernizing a firm or turning labor skilled needs to be borne every (continuous) period. The assumption might be particularly challenging for labor. However, we can see it as a simplification of a more complex demographic process at which units of labor are being replaced and they remain unskilled y they do not invest in educating themselves. Since we focus on proportions and representative families instead of on particular labor units, the simplification seems harmless.**

**In the next section, we discuss the related literature. In section 3, we describe the economy and characterize the equilibrium. Section 4 incorporates evolutionary dynamics to study the evolution of industrialization and training. In Section 5, we analyze the stability of steady states and define the industrialization frontier. Section 6 examines the three public policy domains and their coordination. Final Remarks are presented in Section 7. Two appendices are pre-**

**sented at the end of the document on: a) stability analysis and b) comparative statics.**

## 2 Related Literature

**We analyze industrial policy as a set of economic policy measures that provide a solution to the poverty trap that may arise as a coordination failure. We consider modeling an economy similar to the one described by Rodrik ([34]), but substituting capital intensivity of the modern sector by a fixed labor cost and imperfect trade by an aggregate demand externality, as in Murphy, Sleifer and Visny ([30]).**

The model by Murphy, Sleifer and Visny ([30]) has been also been developed to include: intermediate goods (Yamada [41]); state-owned enterprises (Bjorvatn and Coniglio [10]); oligopoly competition and an open economy (Kreickemeier and Wrona [25]); and a replicator dynamic in the choice of technology (Mendoza-Palacios and Mercado [28]); among others. However, we are not aware of any theoretical model that focuses on the coordination between several economic policy domains. Other dynamic models of techonological choice have studied: path dependent inefficiency (Arthur [7]), poverty traps in a game (Accinelli and Sanchez-Carrera [3]), etc. The dynamics of the economy we model show similarities with those analyzed by Sanchez-Carrera ([36]), particularly with respect to the characterization of the poverty trap based on imitative dynamics. Our modelization of an economy, instead of a game, allows us to characterize an industrialization frontier and a different set of policy domains.

We asssume that trained labor only yields greater productivity in modernized firms. As, Greenwald and Stiglitz ([22]) argue, the benefits of human capital accumulation are far greater in a modernized industrial economy as compared to a traditional one, composed by agriculture and craftery. Consequently, there may not be marginal effects of human capital accumulation on productivity as in Uzawa [40] and Lucas [27]. It has been found evidence of this lack of marginal effects from human capital accumulation to productivity (see Pritchett [32] and Bills and Klenow ([9]).

**The model is consistent with the factor biased technological change (see Acemoglu [1]), although the positive effect of high-skilled labor on technological modernization may depend on the state of the economy and the position of the industrialization frontier. Therefore, although the model may explain the positive relationship between education and industrialization as in France during XIXth century found by Franck and Galor ([21]) it also allows a dynamic deskilling process along with the industrialization (Acemoglu [2]). The dynamics of the scenario of industrialization without qualification is consistent with a reduction of the expected income of the skilled labor, as it has happened in Mexico, inserted into a low-wage labor**

**specialization, during the last decades (see El Colegio de México [14] pp.35-36).**

**Skill bias technology selection due to the complementarity between production factors has been documented by Caselli and Coleman ([12]). Similar to them and to Acemoglu ([1]), we find that the technology choice depends on the relative price of production factors. Instead of focusing on the existence of one or various equilibria, we analyze the dynamics of the economy and how can it transit into a modern industrialized economy.**

**We use replicator dynamics on variables for which the optimization decision may respond to a longer term than production/consumption ones, due to the fixed costs involved. Considering evolutionary assumptions for long-run optimization decisions, while keeping market clearance conditions for prices and quantities make sense are consistent with the recommendations by Nelson and Winter ([31]). However, we do not assume a Schumpeterian competition as in, for instance, Fatas-Villafranca et al. ([20]). Also, from a Neoschumpeterian perspective, Dosi et al. ([17]) relate aggregate demand to evolutionary dynamics to include business cycles. Our reference to aggregate demand does not motivate Keynesian business cycles.**

## 3 The economy

### 3.1 Households behavior

We consider an economy composed by $N$ consumption goods or sectors. A representative household establishes a demand function for each good. Also, households select their level of skills to be utilized in the production of goods by a firm.

#### *3.1.1 Aggregate demand*

We assume that households have identical preferences, so we characterize their demand behavior though a representative consumer with preferences consistent with a Cobb-Douglas utility function, that is

$$u(x_1, x_2..., x_N) = x_1 x_2 \cdots x_N. \tag{1}$$

Let $y$ be the *aggregate income*, which will be defined in (21), and let $p_1, ..., p_N$ be a system of prices, where $p_i$ is the *price of the good* $i = 1, ..., N$. Then the consumer's problem is to maximize his/her utility function (1) subject a budget constraint

$$p_1 x_1 + ... + p_N x_N = y. \tag{2}$$

Hence, the *demand function* for the good $i$ is

$$x_i = \frac{y}{N p_i}. \tag{3}$$

### *3.1.2 Training and productivity*

Each household chooses the level of his/her *skill* to be used in the production of goods in some firm. There are two possible levels of skills: *high* and *low*. Initially, households supply $L$ fixed units of *low-skilled labor* inelastically.

In order $l_h$ units of high-skilled labor to be supplied, the household has to train and spend or loss $(1-\kappa)l$ units low-skill labor, where $0 \leq \kappa \leq 1$, and $l \in [0, L]$. In other words

$$l_h = \kappa l, \quad \text{with } \kappa \in [0,1], \; l \in [0, L]. \tag{4}$$

Let $\gamma_h$ be the proportion labor units that are supplied as high-skilled, and $\gamma_l$ those that are supplied as low-skilled. By construction,

$$\gamma_h + \gamma_l = 1, \qquad \text{with} \;\; \gamma_h, \gamma_l \in [0,1]. \tag{5}$$

So, households supply $\gamma_h \kappa L$ high-skilled labor units and $\gamma_l L$ low-skilled labor units. We define an *effective labor unit* as a unit of labor that may be high-skilled or low-skilled, so a unit of that depends on the supply of low-skill labor and the training costs. Using (4) and (5), if a households supplies $l_e$ units of effective labor, then

$$\begin{aligned} l_e &= [\gamma_h \kappa + \gamma_l] l \\ &= [\gamma_h \kappa + (1-\gamma_h)] l \\ &= [1 - \gamma_h (1-\kappa)] l. \end{aligned} \tag{6}$$

By (6), the total units of effective labor is

$$L_e = [1 - \gamma_h (1-\kappa)] L. \tag{7}$$

## 3.2 Firms Behavior

As Boon ([11]) and Stewart ([39]), we consider that firms choose their technology to produce a good, either a traditional or a modern technology. We assume that each sector $i$ is represented by a firm which decides the type of technology. That is, each sector uses only one type of technology.

Firms only demand effective labor units and they cannot differentiate ex-ante between low or high-skilled labor units in their hiring. However, ex post, the requirement of marginal input in modern firms distinguishes between high and low-skilled labor units.

### *3.2.1 Traditional firms*

If the firm produces the good under a *traditional technology* it is called *traditional firm*. As Murphy-Shleifer-Vishny [30] and Basu [8] we assume perfect competition market for traditional firms. They transform one unit of effective labor $l_{e,i}$ into one unit of output $z_i$:

$$z_i = l_{e,i}. \tag{8}$$

That is, a traditional technology does not distinguish between units of high or low-skilled labor, so we assume that each unit of labor receives a wage $w_\tau$ in any traditional sector. The profit of a traditional firm is given by

$$\pi_{\tau,i} = p_i z_i - w_\tau l_{e,i}. \tag{9}$$

**Notice that if the firms decides on $l_{e,i}$, in order to keep a positive smaller than infinity supply consistent with a profit maximization problem, we need:**

$$p_i = w_\tau. \tag{10}$$

**Thus, any production level would be consistent with profit maximization.**

### *3.2.2 Modern firms*

*Modern firms* are those that chose a *modern technology* for their production. In this case, we assume economies of scale at firm level (as Murphy-Shleifer-Vishny [30] and Basu [8]), but no scope economies nor firms with multi-sectoral operations. The technology improvement is the same in all sectors, involving a fixed labor input of $F$ that does not distinguish whether they are high-skilled or low-skilled. In contrast, the marginal input requirement distinguish between units of high-skilled and low-skilled labor as follows:

*i)* $c \in (0, 1)$ per unit produced, if the labor input is low-skilled; and
*ii)* $c\sigma$, with $\sigma \in (0, 1)$, per unit produced, if the labor input is high-skilled.

In this case $1/c > 1$ is the labor productivity induced by the technology and $1/\sigma > 1$ is the labor productivity induced by the training.

Moreover, each modern firm employs $l_{e,i}$ effective labor units and it is not capable to differentiate ex-ante between a low-skilled or high-skilled labor unit in its hiring. So, we will not consider contingent contracts that may allow modern firms to identify high-skilled workers. Similarly, we will not consider any screening or signaling mechanism. This can be justified if we assume that the firm needs a long time to learn how to select its human resources. As a consequence, low and high-skilled labor units will be assigned randomly according to their existing proportions. We are assuming that firms are neutral towards risk, so that we can focus on expected profits. Similarly, firms cannot optimize when covering the fixed cost. These assumptions allow us to avoid discontinuities.

Let $\gamma$ be the probability of hiring one unit of high-skilled labor after eliminating the $(1 - \kappa)L$ wasted units of labor due to the training process. Using Bayesian formula to calculate $\gamma$ we have that

$$\gamma := \frac{\gamma_h \kappa}{\gamma_h \kappa + (1 - \gamma_h)}, \tag{11}$$

In addition, we assume that the match between the types of firms and types of skills is completely random. Thus, for the production of a quantity $z_i$ of goods and a demand of $l_{e,i}$ effective labor units in sector $i$, a modern firm hires:

*i*) with a probability $\gamma$, an input of high-skilled labor given by $F + c\sigma z_i$;
*ii*) and with a probability $(1-\gamma)$, an input of low-skilled labor given by $F+cz_i$.

We assume that modern firms maximize their price in their respective markets while avoiding the entry of traditional firms. Since, at $p_i > w_\tau$ traditional firms would obtain positive profits entering a production at which they do not have fixed costs, the preceding implies that $p_i = w_\tau$ in modern markets (sectors). Given a demand $z_i$, a modern firm produces with economies of scale, after a fixed input of $F$ of effective labor, so it may incur in positive or negative expected profits. The effective labor units are identified as low or high skilled labor units, ex-post, after hiring, (this could be the consequence of some conditional bonus). We assume that a modern firm in sector $i$, pays a wage $w_\mu > w_\tau$ for a low-skilled labor unit and $w_\mu + \omega > w_\tau$ $(\omega > 0)$ for a high-skilled labor unit. Then for a given price $p_i$ and a demand $z_i$ its *expected profit* is given by

$$\begin{aligned}\pi_{\mu,i} &= p_i z_i - w_\mu(1-\gamma)l_{e,i} - (w_\mu+\omega)\gamma l_{e,i}\\ &= p_i z_i - (1-\gamma)w_\mu(F+cz_i) - \gamma(w_\mu+\omega)(F+c\sigma z_i).\end{aligned} \tag{12}$$

The process of industrialization (as in Mendoza-Palacios and Mercado [28]) is a transition from a traditional to a modern industry. If the representative firm of the sector $i$ is a modern firm, we say that the sector $i$ has been industrialized. From equations (3), (10) and (12), if a sector $i$ is industrialized then the expected profit of a modern firm is

$$\pi_{\mu,i} = \left(1 - (1-\gamma)\frac{w_\mu}{w_\tau}c - \gamma\frac{(w_\mu+\omega)}{w_\tau}c\sigma\right)\frac{y}{N} - w_\mu F - \gamma\omega F \tag{13}$$

Note that we need the following conditions

$$\frac{w_\mu}{w_\tau} < \frac{1}{c}, \tag{14}$$

$$\frac{w_\mu+\omega}{w_\tau} < \frac{1}{c\sigma}, \tag{15}$$

for a possible $\pi_\mu \geq 0$, which are satisfied if

$$w_\mu + \omega < \frac{w_\mu}{\sigma} < \frac{w_\tau}{c\sigma}. \tag{16}$$

Moreover, if (16) is satisfied, then we have that

$$\frac{(w_\mu+\omega)}{w_\tau}c\sigma < \frac{w_\mu}{w_\tau}c. \tag{17}$$

In other words, for a modern firm the marginal cost of a high-skilled labor unit is lower than the marginal cost of a low-skilled labor unit.

Let $n$ be the number of representative firms that choose a modern technology. Then the proportion of firms choosing a modern technology is described by $\lambda_\mu := \frac{n}{N}$, and the proportion of firms choosing a traditional technology is described by $\lambda_\tau := 1 - \lambda_\mu$. Therefore

$$\lambda_\mu + \lambda_\tau = 1, \qquad \text{with} \quad \lambda_\mu, \lambda_\tau \in [0, 1]. \tag{18}$$

Finally, the sum of expected profits of $n$ representative firms that choose a modern technology is

$$\sum_{i=1}^{n} \pi_{\mu,i} = \lambda_\mu N \left[ \left( 1 - (1-\gamma) \frac{w_\mu}{w_\tau} c - \gamma \frac{(w_\mu + \omega)}{w_\tau} c\sigma \right) \frac{y}{N} - w_\mu F - \gamma \omega F \right]. \tag{19}$$

## 3.3 Equilibrium analysis

In this section we describe the equilibrium of the model, which is a modified version of Murpy-Shleifer-Vishny model [30] and a direct extension of Basu [8].

### *3.3.1 The equilibrium*

The equilibrium of the model is determined by the following definition.

**Definition 1** Given a vector $(\lambda_\mu, \gamma_h)$, we define an equilibrium as a vector of prices $(p_1, ..., p_N, w_\tau, w_\mu, \omega)$ and allocations $(x_i, z_i, l_{e,i})_{i=1}^{N}$ such that

**A1** The representative household maximizes utility (1) given an income (2), and supplies $L_e = [1 - \gamma_h(1-\kappa)]L$ units of effective labor.

**A2** Each type of firm maximizes its profit as follows:
- *i)* a firm in a traditional sector maximizes (9) and it has a profit equal to zero;
- *ii)* **a firm in a modern sector selects $p_i$ to maximize its expected profit (12) and avoid the entrance of traditional firms.**

**A3** Markets clear, that is:

$$x_i = z_i, \qquad i = 1, ..., N; \tag{20}$$

$$\sum_{i=1}^{N} l_{e,i} = L_e. \tag{21}$$

### *3.3.2 Determination of equilibrium*

The equilibrium (see Definition 1) is calculated by solving the simultaneous solution of (3), (12), and (20)-(23).

**A1** implies that the demand of sector $i$ is given by (3). Then, by **A2** and **A3** (specifically (20)), we have that

$$w_\tau = p_i, \quad i = 1, ..., N \tag{22}$$

Let $\lambda_\mu = \frac{n}{N}$ be the proportion of firms that choose a modern technology, as in (18). By (8), (20) and (22), each traditional firm in a given market uses $\frac{y}{Nw_\tau}$ units of labor. Hence, given $\lambda_\mu$, the economy uses $(1-\lambda_\mu)\frac{y}{w_\tau} = (N-n)\frac{y}{Nw_\tau}$ units of effective labor units in the traditional sector, and by (21) $L_e - (1-\lambda_h)\frac{y}{w_\tau}$ units of effective labor units in the modern one. So, the aggregate income when $\lambda_\mu$ sectors are industrialized is

$$\begin{aligned} y = \sum_{i=N-n+1}^{N} \pi_{\tau,i} + \sum_{i=1}^{N-n} \pi_{M,i} + w_\tau \left[(1-\lambda_\mu)\frac{y}{w_\tau}\right] \\ + w_\mu \left[(1-\gamma)\left(L_e - (1-\lambda_\mu)\frac{y}{w_\tau}\right)\right] \\ + (w_\mu + \omega)\left[\gamma\left(L_e - (1-\lambda_\mu)\frac{y}{w_\tau}\right)\right] \end{aligned} \tag{23}$$

where $\pi_{\tau,i} = 0$, for $i = (N-n)+1, ...N$ and $\sum_{i=1}^{N-n} \pi_i^M$ is described by (19).

Solving for $y$ in (23) we obtain

$$y = \frac{[L_e - nF]Nw_\tau[w_\mu + \omega\gamma]}{n[(1-\gamma)w_\mu c + \gamma(w_\mu+\omega)c\sigma] + (w_\mu + \omega\gamma)(N-n)}. \tag{24}$$

Given $\lambda_\mu$, then using (24) in (13) we obtain that the profit of a modern firm is

$$\pi_\mu = \frac{(w_\tau - (1-\gamma)w_\mu c - \gamma(w_\mu+\omega)c\sigma)\left(\frac{L_e}{NF} - \lambda_\mu\right)(w_\mu + \omega\gamma)F}{\lambda_\mu[(1-\gamma)w_\mu c + \gamma(w_\mu+\omega)c\sigma] + (w_\mu+\omega\gamma)(1-\lambda_\mu)} - (w_\mu + \gamma\omega)F \tag{25}$$

If all firms are industrialized, then the economy must supply at least $NF$ units of effective labor so that the profits in the modernized sectors can be positive, that is

$$L_e > NF. \tag{26}$$

## 4 Industrialization and training processes

In this section we aggregate dynamics to explain the evolution of industrialization and training processes. Section 4.1 introduces imitative-evolutionary dynamics that explain how firms and households take their decisions about both the technology change and job skill transition, respectively. In section 4.2 we analyze how the imitative dynamics affect the principal variables of the economy.

### 4.1 Evolution of industrialization and training

We assume that firms select the type of technology to be used, whether it is traditional or modern over time, in a dynamic behavior. Similarly, households decide on supplying their labor units as high or low-skilled. This is incorporated in the model through imitative evolutionary dynamics. That is, each firm selects a technology if it observes that its' profit (when using such technology) is higher than the average profit of the whole population of firms; and similarly for households' training decisions. We opted for an imitative evolutionary dynamics known as the replicator dynamics, which has a simple mathematical form and a natural interpretation (see, for example, Hofbauer and Sigmund [23], and Sandholm [37]). Krugman [26], for instance, uses replicator dynamics to induce a dynamic behavior in a static spatial economic model.

**We will be assuming that modern firms must face fixed labor cost $F$ every period. Similarly, households must cover their training cost every period to keep their high skilled labor. This simplification can be approached by assuming that we had numerous generations and if the new generation did not face the training cost, the proportion of high-skilled labor would be reduced. Since we are focusing on the proportions, the simplification seems closer to its dynamics than assuming that high-skilled labor units remain so. In addition, such an approach allows us to explore skill losing processes.**

In replicator dynamics, using (5) and (18) for every time, the evolution of industrialization and training processes are described as follows:

*i)* Industrialization process

$$\dot{\lambda}_\mu = [\pi_\mu - \bar{\pi}]\lambda_\mu, \tag{27}$$

$$\dot{\lambda}_\tau = [\pi_\tau - \bar{\pi}]\lambda_\tau. \tag{28}$$

*ii)* Training process

$$\dot{\gamma}_h = [w_h - \bar{w}]\gamma_h, \tag{29}$$

$$\dot{\gamma}_l = [w_l - \bar{w}]\gamma_l. \tag{30}$$

where $\pi_\tau$ is the profit of a traditional firm (so $\pi_\tau = 0$), $\pi_\mu$ is the expected profit of a modern firm described by (25), and

$$\begin{aligned}\bar{\pi} &:= \lambda_\mu \pi_\mu + (1-\lambda_\mu)\pi_\mu \\ &= \lambda_\mu \pi_\mu. \end{aligned} \tag{31}$$

On the other hand, $w_h$ and $w_l$ are the average incomes of, respectively, each high-skilled and low-skilled labor unit; then, $\bar{w}$ is the average income, that is

$$w_h = \kappa(\lambda_\mu(w_\mu + \omega) + (1-\lambda_\mu)w_\tau) \tag{32}$$

$$w_l = \lambda_\mu w_\mu + (1-\lambda_\mu)w_\tau \tag{33}$$

$$\bar{w} = \gamma_h w_h + (1-\gamma_h)w_l. \tag{34}$$

Notice that we need the condition

$$\kappa(\omega + w_\mu) > w_\mu, \tag{35}$$

so that when all the firms are industrialized, which maximizes the expected income of a high skilled labor unit, obtaining training is preferable to not doing so. Otherwise, $\dot{\gamma}_h$ would always be negative.

## 4.2 Training and technological changes in the economy

We can simplify the system (27)-(28) by substituting (31) in (27), and by using (18) to obtain the *technological transition equation* (36), which explains the technological change process. Similarly, we simplify the system (29)-(30), using (5) and (32)-(35) in (29) to obtain the *job skill transition equation* (37).

The evolution of the technological change affects directly the economy as follows:

*technological transition equation*

$$\dot{\lambda_\mu} = \lambda_\mu(1-\lambda_\mu)\pi_\mu(\lambda_\mu, \gamma_h); \tag{36}$$

*job skill transition equation*

$$\begin{aligned} \dot{\gamma_h} &= \gamma_h(1-\gamma_h)[w_h(\lambda_\mu) - w_l(\lambda_\mu)] \\ &\gamma_h(1-\gamma_h)[\kappa\lambda_\mu\omega - (1-\kappa)(\lambda_\mu w_\mu + (1-\lambda_\mu)w_\tau]; \end{aligned} \tag{37}$$

*aggregate income*

$$y(\lambda_\mu, \gamma_h) = \frac{[L_e - \lambda_\mu F]Nw_\tau[w_\mu + \omega\gamma]}{\lambda_\mu[(1-\gamma)w_\mu c + \gamma(w_\mu+\omega)c\sigma] + (w_\mu + \omega\gamma)(1-\lambda_\mu)}; \tag{38}$$

*demand of of good i*

$$x_i(\lambda_\mu, \gamma_h) = \frac{y(\lambda_\mu, \gamma_h)}{Nw_\mu}; \tag{39}$$

*aggregate welfare function*

$$u(\lambda_\mu, \gamma_h) = x_1 x_2 \cdots x_N; \tag{40}$$

*expected profit of modern firm*

$$\pi_\mu(\lambda_\mu, \gamma_h) =$$

$$\frac{(w_\tau - (1-\gamma)w_\mu c - \gamma(w_\mu+\omega)c\sigma)\left(\frac{L_e}{NF} - \lambda_\mu\right)(w_\mu + \omega\gamma)F}{\lambda_\mu[(1-\gamma)w_\mu c + \gamma(w_\mu+\omega)c\sigma] + (w_\mu+\omega\gamma)(1-\lambda_\mu)} - (w_\mu + \gamma\omega)F; \tag{41}$$

## 5 Steady states and stability

### 5.1 Stability analysis

Let us study the steady states of the economy, that is, those cases where all the state variables, $(\lambda_\mu, \gamma_h)$ in the system (36)-(37), remain invariant, i.e., $\dot{\lambda}_\mu = 0$ and $\dot{\gamma_h} = 0$. The steady states will help us to define an industrialization frontier, above from which a full industrialization can be achieved through the dynamics of the economy.

Assume that (16) and (26) are satisfiyed, as well as

$$w_\mu > (w_\tau - w_\mu c)\,\frac{L}{NF} > \frac{w_\tau}{\kappa}. \tag{42}$$

Consider (35) and

$$\left(\frac{w_\tau - (w_\mu + \omega)c\sigma}{w_\mu + \omega}\right)\frac{\kappa L}{NF} > 1; \tag{43}$$

then, Table 1 summarizes the stability results of steady states.

**Table 1 Stability results of the steady states.**

| **Steady state** $(\lambda_\mu, \gamma_h)$ | **If (35) is satisfied** | **If (35) is not satisfied** |
|---|---|---|
| $(0,0)$ | **attractor** | **attractor** |
| $(0,1)$ | unstablee[1] | unstable[1] |
| $(1,0)$ | saddle | **attractor** |
| $(1,1)$ | **attractor** | saddle |
| $(\lambda^*_{\mu 0}, 0)$, $\lambda^*_{\mu 0}$ as in (44) | unstable[2] | saddle |
| $(\lambda^*_{\mu 1}, 1)$, $\lambda^*_{\mu 1}$ as in (45) (*) | unstable[2] | repeller |
| $(\lambda^*_\mu, \gamma^*_h)$, $\lambda^*_\mu$ as in (46) and $\gamma^*_h$ as in (47) | unstable[2] | unstable[2] |
| An unstable steady state implies that it is not stable, that is, it may be saddle or repeller. We consider the following cases: 1.-steady state is repeller if condition (43) is satisfies and saddle if it is not; 2- it is not possible classified the unsuitability of the steady state. | | |
| (*) This steady state only there exists if $\lambda^*_{\mu 1}$ in (45) is positive. | | |

Where,

$$\lambda^*_{\mu_0} = \frac{w_\mu}{(w_\mu - w_\tau)} - \frac{(w_\tau - w_\mu c)}{(w_\mu - w_\tau)}\frac{L}{NF}, \tag{44}$$

$$\lambda^*_{\mu_1} = \frac{(w_\mu + \omega)}{(w_\mu + \omega) - w_\tau} - \frac{w_\tau - (w_\mu + \omega)c\sigma}{(w_\mu + \omega) - w_\tau}\frac{\kappa L}{NF}, \tag{45}$$

$$\lambda^*_\mu = \frac{(1-\kappa)w_\tau}{\kappa\omega - (1-\kappa)(w_\mu - w_\tau)}, \tag{46}$$

$$\gamma^*_h = \frac{-b \pm \left(b^2 - 4ac\right)^{1/2}}{2a}, \tag{47}$$

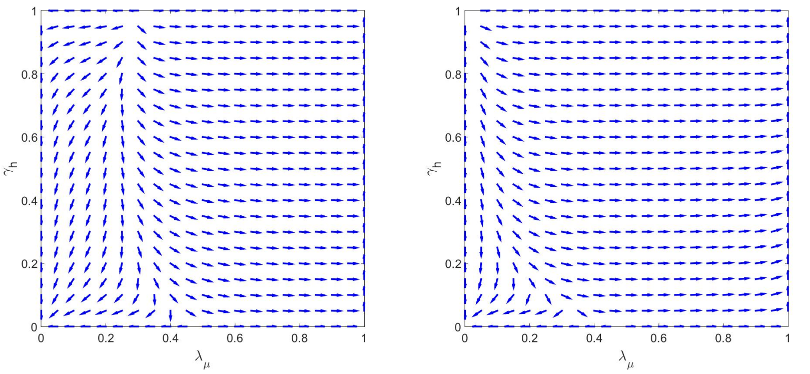
and

$$
\begin{aligned}
a &= -\left[\frac{(1-\kappa)L}{NF}\right]\left[\kappa[w_\mu c - (w_\mu+\omega)c\sigma] - (1-\kappa)[w_\tau - w_\mu c]\right],\\
b &= \kappa[[w_\mu c - (w_\mu+\omega)c\sigma]L/(NF) - \omega(1-\lambda_\mu^*)]\\
&\quad -(1-\kappa)[[w_\tau - w_\mu c]L/(NF) - [\lambda_\mu^* w_\tau + w_\mu(1-\lambda_\mu^*)]],\\
c &= [w_\tau - w_\mu c]L/(NF) - [\lambda_\mu w_\tau + w_\mu(1-\lambda_\mu)].
\end{aligned}
$$

The steady state $(0,0)$ is an attractor and constitutes a poverty trap of the economy; if no firm in the economy is modernized and no labor is trained, the effort needed to achieve paths that drive the economy to a full industrialization is high. Whether $(1,1)$ is an attractor steady state or not depends on condition (35) being satisfied; that is, on training being profitable in the most favorable full industrialization environment. Otherwise, training would never be profitable individually or collectively and industrialization without qualification, i.e. $(1,0)$ becomes an attractor steady state.

## 5.2 The industrialization frontier

The *industrialization frontier* links the unstable steady states $(0,1)$, $(\lambda_{\mu 1}^*,1)$, $(\lambda_\mu^*,\gamma_h^*)$, and $(\lambda_{\mu 0}^*,0)$ in Table 1. Any trajectory with an initial state at the right of the industrialization frontier evolves to an economy with positive growth rate of the aggregate income and where $\lambda_\mu = 1$. Otherwise, the trajectories drive the economy toward $(0,0)$.



(a) Dynamics of $\lambda_\mu$ and $\gamma_h$ if $\lambda_{\mu 1}^* > 0$. (b) Dynamics of $\lambda_\mu$ and $\gamma_h$ if $\lambda_{\mu 1}^* \leq 0$.

**Fig. 1** Dynamics of $\lambda_\mu$ and $\gamma_h$ if (35) is satisfies. The value of parameters are in the Appendix B.3, see Table 4

Both phase diagrams of trajectories in Figure 1 show industrialization frontiers (notice that in subfigure (b) $\lambda_{\mu 1}^\star \leq 0$), such that above from them the

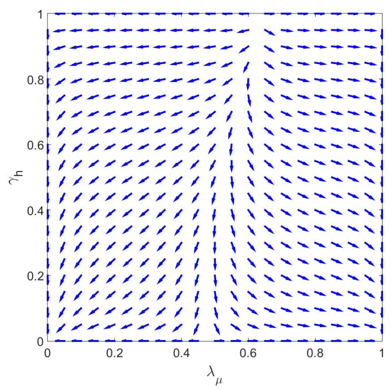


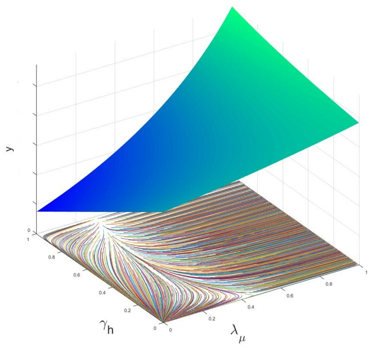

**Fig. 2** The Dynamics of $\lambda_\mu$ and $\gamma_h$ if (35) is not satisfied. The value of parameters are in the Appendix B.3, see Table 4

imitative dynamics drive the economy to a full industrialization with complete high-skilled labor. **This dynamics would reflect the successful Korean industrialization of the second half of the XXth century. Although we are not considering exports, which played a huge role to absorb the extra production of the modernized industries, Korea managed to induce a virtuous circle between modernized firms and educated labor, instead of focusing on its comparative advantage (see Amsden [6]).**

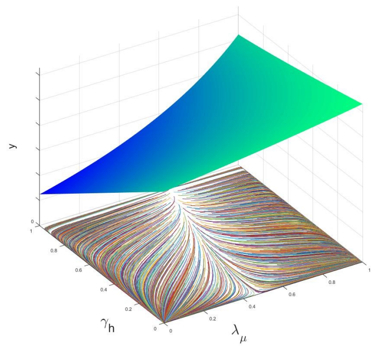
On the contrary, in Figure 2 we can observe a phase diagram at which $(\lambda_\mu, \gamma_h) = (1, 1)$ is not steady state and, therefore, to the right of the industrialization frontier we only reach dynamics that lead the economy to a full industrialization without high-skilled labor.

As we can observe in Figure 3, the dynamics of the economy may help to enhance $y$. Increasing $\lambda_\mu$ has a positive effect on $y$, for any given $\gamma_h$. However, this is not the case for $\gamma_h$, since overcoming the cost of training human resources only yields when there are sufficient modern firms that hire trained workers. That is why, when starting from an initial state $(0, \gamma_h > 0)$ there will be a growth of $y$ over the time; but one needs to keep in mind that the economy is caught in the poverty trap and getting further away from a full industrialization. Subfigure (b) shows that when (35) is not satisfied, training is never optimal and $y$ is maximized at the steady state in $(1, 0)$.

**The preceding dynamics may be compatible with the maquila industrialization that has experienced Mexico during the recent decades. The behavior of the Mexican macroeconomic figures are compatible with those considered in the model: a positive, but small, economic growth and a fall in the expected income of the most educated (see COLMEX [14]). Then, according to the model, such low economic growth would be related to a lack of an industrialization that relied on the productivity of the educated labor.**




(a) If (35) is satisfied.




(b) If (35) is not satisfied.

**Fig. 3** Dynamics of $\lambda_\mu$, $\gamma_h$ and $y$.

## 6 Industrialization process and coordination

As we have seen, the achievement of a full industrialization depends on the position of the initial state with respect to the industrialization frontier. For all of the above, we are interested in the parameters that affect the industrialization frontier relative to the initial state. For this purpose, we analyze three domains of the industrial policy:

*i*) innovation policies;
*ii*) polices of human resources training, wages and employment; and
*iii*) push policies.

We name industrial policy to a combination and coordination of the preceding policies.

### 6.1 Innovation policies

Innovation policies refer to changes in $N$, $F$, $c$ and $\sigma$, which characterize the modernizing technology and the aggregate demand externality, which affect the position of the industrialization frontier. Table 2 and Figure 4 [1] show how facing a technology with low fixed costs, high productivity or focusing the intervention in economies with fewer sectors, will bring the industrialization frontier closer to the origin. Then, innovation policy should focus on three aspects: reducing fixed costs, although this can be relaxed according to the size of the economy ($L$ and $N$ so that (26) holds); evaluate the productivity improvements induced by new technologies ($c$ and $\sigma$); and the promotion for regional and sectoral policies to reduce $N$.

[1] Notice that for all the phase diagrams in Figure 4 condition 35 is satisfied.

**Table 2 Industrialization frontier displacement due to changes of $\sigma, c, F$ and $N$**

| **Value of $\lambda_\mu$ in a steady state** | $\sigma$ | $c$ | $F$ | $N$ |
|---|---|---|---|---|
| $\lambda^*_{\mu 0}$ as in (44) | 0 | + | + | + |
| $\lambda^*_{\mu 1}$ as in (45) | + | + | + | + |
| $\lambda^*_{\mu}$ as in (46) | 0 | 0 | 0 | 0 |

The table show the sing of partial derivatives of $\lambda_\mu$ in the steady state, respect to the variable in the column:
+ partial derivative is positive;
− partial derivative is negative;
0 partial derivative is equal to zero.

From historical experiences, we can observe how countries have sometimes invested into new technologies creating new comparative advantages, such as the steel sector during the take-off of the the Republic of Korea during the 1970s and 1980s (D'Costa [15]). However, as we can observe in the model, modernizing by introducing a high fixed cost technology ($F$), as it is with the iron and steel industry, moves the industrialization frontier away. That makes the industrialization more costly, which may explain the intensification of the autocracy in the Korea during its Fourth Republic (1972-81) or the complications during the Great Leap Forward, which led to the loss of a great number of lives in China.

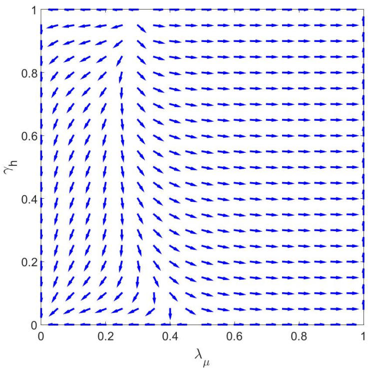
On the other hand, focusing the industrial policy, regionally and sectorally, may help to reduce the externality through aggregate demand ($N$). That would explain clustering strategies, both sectorally and regionally, being more successful, as it seems to be the case in Germany (see Sternberg and Litzenberger [38]). Similarly, if economic complexity is related to market size, the model points out to one of the advantages of smaller countries when applying industrial policy, which should be a variable to take into account when discussing the optimality of the size of a country (see Alesina [4]).

### 6.2 Polices of human resources training, wages and employment

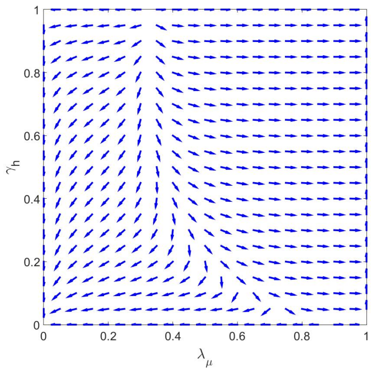
The second domain of policies also affects the parameters of the model, particularly the position of the industrialization frontier and condition (35): wages ($w_\mu$, $\omega$); human resources training cost ($\kappa$); and labor supply ($L$). Table (3) and Figure 5[2] illustrate how these variables affect the industrialization frontier, while their effect on condition (35) is straightforward.

The model points out to the importance of reducing the training cost ($1-\kappa$), for example, by focusing on short vocational training. Wages need to keep a balance to induce both firms being modernizing and households training; that is, keeping conditions (16) and (35). Notice that $L$ is fully employed in the model; therefore, within the policies that affect $L$, we should also include those that improve employability.

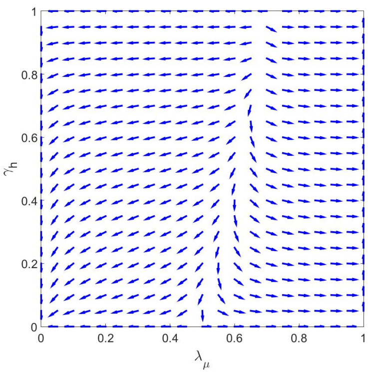
[2] Notice that for all the phase diagrams in Figure 5 condition 35 is satisfied.



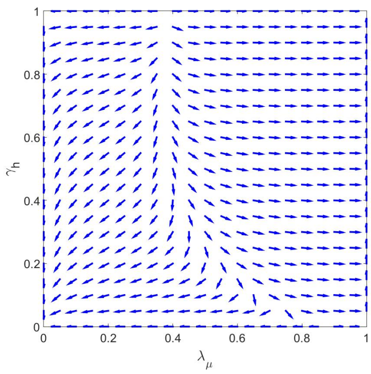

(a) Original dynamics.



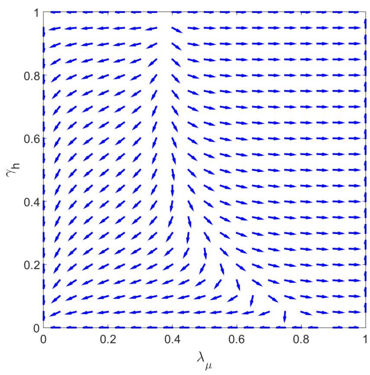

(b) Dynamics with increments in $c$.




(c) Dynamics with increments in $\sigma$.




(d) Dynamics with increments in $F$.




(e) Dynamics with increments in $N$.

**Fig. 4** Dynamics with value changes in $c, \sigma, F$ and $N$. The value of parameters are in the Appendix B.3, see Table 5

The effect of the reduction of the training cost is consistent with the success of vocational systems, such as the German case, when creating a qualified labor

**Table 3 Industrialization frontier displacement due to changes of $L, \kappa, w_\mu$ and $\omega$**

| **Value of $\lambda_\mu$ in a steady state** | $L$ | $\kappa$ | $w_\mu$ | $\omega$ |
|---|---|---|---|---|
| $\lambda^*_{\mu_0}$ as in (44) | $-$ | 0 | $+$ | 0 |
| $\lambda^*_{\mu_1}$ as in (45) | $-$ | $-$ | $+$ | $+$ |
| $\lambda^*_{\mu}$ as in (46) | 0 | $-$ | $+$ | $-$ |

The table show the sing of partial derivatives of $\lambda_\mu$ in the steady state, respect to the variable in the column:
$+$ partial derivative is positive;
$-$ partial derivative is negative;
0 partial derivative is equal to zero.

force that is attractive to firms that, at the same time, offer them back good job opportunities (see Reinhard et al. [33]).

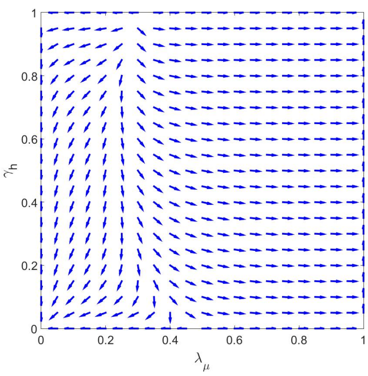
In the model there are no marginal effects of human capital accumulation for all the states, which is consistent with the absence of economic growth in countries where there has been human capital accumulation (see Pritchett [32]). Our model offers two possible explanations for this. First, if the foreign aid is a direct support (for example a scholarship program) and it does not reduce the training cost (the opportunity cost may be the most important cost in training programs), we can see it as a push policy that does not change the position of the industrialization frontier. Second, in the absence of modern firms that offer $\omega$ or if that bonus is not high enough, workers have not incentives to be trained (see Figure 2).

### 6.3 Push policies and coordination

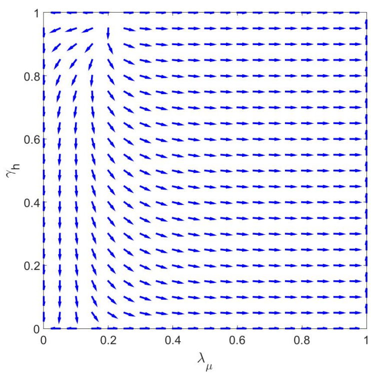
We define push policies in the model as an induced change in the initial state of the economy $(\lambda_\mu, \gamma_h)$. Since we are assuming an externality through aggregate demand, pushing the steady state means to induce a greater coordination to overcome the inefficiency due to such externality. From Big Push models (see Murphy et al. [30]), an industrialization process is characterized as a change in the fraction of industries that are modernized. In our model, such policy could be described as a change in $\lambda_\mu$; i.e., an horizontal shift in the phase diagram. As we can observe in the phase diagrams, an increase solely in $\lambda_\mu$ may require a great effort to overcome the industrialization frontier. However, a combination with an increase on $\gamma_h$ may reduce that effort.

In addition to a change in the state, an industrial policy should seek to influence on the parameters that bring the industrialization frontier closer to the origin, the industrial policy domains analyzed in subsections 6.1 and 6.2, so that entering a path that drives the economy to full industrialization with full high-skills is easier. See Figure 6.

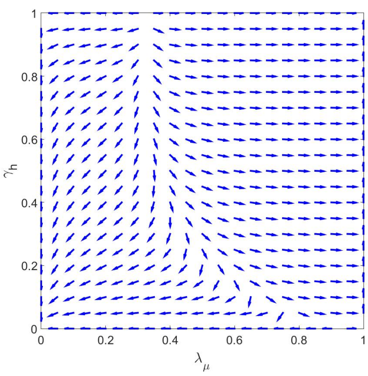
The model is useful to understand why some industrial policies have been successful, thus helping policy makers to design successful policy interventions. For instance, by enriching the number of policy domains which constitute an industrial policy, we can better understand the role played by superministeries



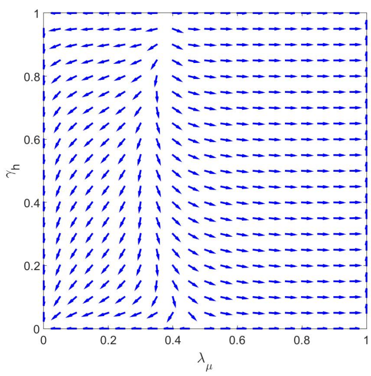

(a) Original dynamics.



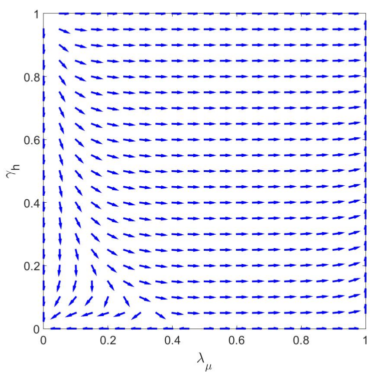

(b) Dynamics with increments in $L$.




(c) Dynamics with increments in $w_\mu$.




(d) Dynamics with increments in $\omega$.

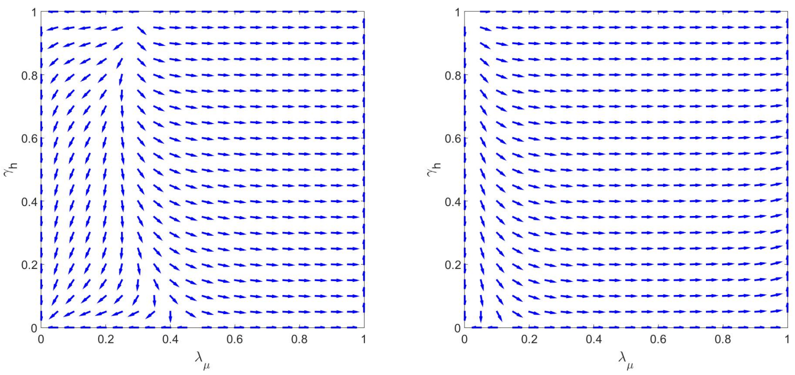



(e) Dynamics with increments in $\kappa$.

**Fig. 5** Dynamics with value changes in $L, w_\mu, \omega$ and $\kappa$.
The value of parameters are in the Appendix B.3, see Table 6

such as the Ministry of International Trade and Industry (MITI) during the

Japanese spectacular economic transformation in the second half of the XXth century (see Johnson [24]). **It is, precisely, the role of these agencies that would help to combine the factors mentioned in the model, instead of assuming that a particular positive effect of modernizing a firm or educating labor is going to be universal.**



(a) Original dynamics. (b) Dynamics with coordination of policies

**Fig. 6** Coordination of policies.The value of parameters are in the Appendix B.3, see Table 7

## 7 Final remarks

The issue of industrialization policy is approached in this paper. It analyzes the effects of coordinating three public policy domains to accelerate industrialization: innovation policy; policy towards human resources training, wages and employment; and push policies. These policies determine, for instance, whether the economy reaches a trajectory from a poverty trap to a full industrialization, or not. There are multiple outcomes of coordination, ranging from unsuccessful equilibrium (remaining in a poverty trap) to successfully industrializing. Concerning this point, the paper emphasizes a coordination of policies as an efficient development strategy.

Our model focuses on evolutionary dynamics, assuming bounded rationality, and considers a heterogeneity of states such that there is a coordination problem to achieve the most desirable one. This approach may be useful to other new studies on the coordination of public policies that affect complementary variables which focus on the transition dynamics.

Considering complementarities between variables that can be affected by public policies reduces the cost of a government intervention. We believe that, although the argument has been recently approached, the dynamic analysis clarifies two important public policy messages. On the one hand, one must be very careful about believing that a policy that focuses on a particular factor will have a similar effect on countries with different states. On the other hand, we claim the importance of the coordination agencies during industrialization processes as key elements to overcome the industrialization frontier and reach successful development paths.

## Appendix

## A Stability analysis

To study the stability of the dynamic system (36)-(37), we will analyze the characteristic polynomial $f(\epsilon) = \det(A - \epsilon I)$, where $\epsilon = (\epsilon_1, \epsilon_2)$, $I$ is the $2 \times 2$-identity matrix and $A$ is the matrix

$$\begin{bmatrix} \frac{\partial G}{\partial \lambda_\mu} & \frac{\partial G}{\partial \gamma_h} \\ \frac{\partial H}{\partial \lambda_\mu} & \frac{\partial H}{\partial \gamma_h} \end{bmatrix} \tag{48}$$

where

$$\begin{aligned}
G(\lambda_\mu, \gamma_h) &:= \lambda_\mu(1-\lambda_\mu)\pi_\mu(\lambda_\mu, \gamma_h), \\
H(\lambda_\mu, \gamma_h) &:= \gamma_h(1-\gamma_h)[\kappa\lambda_\mu\omega - (1-\kappa)(\lambda_\mu w_\mu + (1-\lambda_\mu)w_\tau], \\
\frac{\partial G}{\partial \lambda_\mu} &= \lambda_\mu(1-\lambda_\mu)\frac{\partial \pi_\mu}{\partial \lambda_\mu} + (1-2\lambda_\mu)\pi_\mu, \\
\frac{\partial G}{\partial \gamma_h} &= \lambda_\mu(1-\lambda_\mu)\left[\frac{\partial \pi_\mu}{\partial \gamma}\frac{d\gamma}{d\gamma_h} + \frac{\partial \pi_\mu}{\partial \gamma_h}\right], \\
\frac{\partial H}{\partial \lambda_\mu} &= \gamma_h(1-\gamma_h)[\kappa\omega + (1-\kappa)(w_\tau - w_\mu)], \\
\frac{\partial H}{\partial \gamma_h} &= (1-2\gamma_h)[\kappa\lambda_\mu\omega - (1-\kappa)(\lambda_\mu w_\mu + (1-\lambda_\mu)w_\tau)].
\end{aligned}$$

### A.1 Steady state $(0, 0)$

In this case

$$\left.\begin{bmatrix} \frac{\partial G}{\partial \lambda_\mu} & \frac{\partial G}{\partial \gamma_h} \\ \frac{\partial H}{\partial \lambda_\mu} & \frac{\partial H}{\partial \gamma_h} \end{bmatrix}\right|_{(0,0)} = \begin{bmatrix} \pi_\mu(0,0) & 0 \\ 0 & -(1-\kappa)w_\tau \end{bmatrix},$$

where

$$\pi_\mu(0,0) = [(w_\tau - w_\mu c)(L/(NF)) - w_\mu]F.$$

By (42), $\pi_\mu(0,0) < 0$. In this case

$$f(\epsilon) = (\pi_\mu(0,0) - \epsilon_1)(-(1-\kappa)w_\tau - \epsilon_2),$$

which implies that the steady state $(0, 0)$ is an attractor.

### A.2 Steady state $(0, 1)$

For this steady state

$$\left.\begin{bmatrix} \frac{\partial G}{\partial \lambda_\mu} & \frac{\partial G}{\partial \gamma_h} \\ \frac{\partial H}{\partial \lambda_\mu} & \frac{\partial H}{\partial \gamma_h} \end{bmatrix}\right|_{(0,1)} = \begin{bmatrix} \pi_\mu(0,1) & 0 \\ 0 & (1-\kappa)w_\tau \end{bmatrix},$$

where

$$\pi_\mu(0,1) = F\Big[(w_\tau - (w_\mu + \omega)c\sigma)(\kappa L/(NF)) - (w_\mu + \omega)\Big].$$

We have that

$$f(\epsilon) = (\pi_\mu(0,1) - \epsilon_1)((1-k)w_\tau - \epsilon_2)$$

which implies that the steady state $(1,0)$ is a repeller if (43) is satisfied, and it is a saddle if (43) is not satisfied.

## A.3 Steady state $(1,0)$

In this case

$$\left.\begin{bmatrix} \frac{\partial G}{\partial \lambda_\mu} & \frac{\partial G}{\partial \gamma_h} \\ \frac{\partial H}{\partial \lambda_\mu} & \frac{\partial H}{\partial \gamma_h} \end{bmatrix}\right|_{(1,0)} = \begin{bmatrix} -\pi_\mu(1,0) & 0 \\ 0 & \kappa(w_\mu + \omega) - w_\mu \end{bmatrix},$$

where

$$\pi_\mu(1,0) = \frac{F}{c}[(w_\tau - w_\mu c)(L/(NF)) - w_\tau].$$

Since (42) is satisfied, then $\pi_\mu(1,0) > 0$. Moreover

$$f(\epsilon) = (-\pi_\mu(1,0) - \epsilon_1)(\kappa(w_\mu + \omega) - w_\mu - \epsilon_2).$$

Given $\pi_\mu(1,0) > 0$, if (35) is not satisfied we have that the steady state $(0,1)$ is an attractor. If (35) is satisfied, then it is a saddle.

## A.4 Steady state $(1,1)$

For this steady state

$$\left.\begin{bmatrix} \frac{\partial G}{\partial \lambda_\mu} & \frac{\partial G}{\partial \gamma_h} \\ \frac{\partial H}{\partial \lambda_\mu} & \frac{\partial H}{\partial \gamma_h} \end{bmatrix}\right|_{(1,1)} = \begin{bmatrix} -\pi_\mu(1,1) & 0 \\ 0 & -(\kappa(w_\mu + \omega) - w_\mu) \end{bmatrix},$$

where

$$\pi_\mu(1,1) = \frac{F}{c\sigma}\left[(w_\tau - (w_\mu + \omega)c\sigma)(\kappa L/NF) - w_\tau\right]$$

By (16) and (42),

$$(w_\tau - (w_\mu + \omega)c\sigma)(\kappa L/(NF)) - w_\tau \;>\; (w_\tau - w_\mu c)(\kappa L/(NF)) - w_\tau \;>\; 0,$$

then $\pi_\mu(1,1) > 0$. We have that

$$f(\epsilon) = (-\pi_\mu(1,1) - \epsilon_1)(-(\kappa(w_\mu + \omega) - w_\mu) - \epsilon_2),$$

where $\pi_\mu(1,1) > 0$. Therefore the steady state $(0,1)$ is a saddle if (35) is not satisfied, and it is an attractor if (35) is satisfied.

## A.5 Steady state $(\lambda_{\mu_0^*}, 0)$

Consider $\lambda_{\mu_0^*}$ as in (44). In this case

$$\left.\begin{bmatrix} \frac{\partial G}{\partial \lambda_\mu} & \frac{\partial G}{\partial \gamma_h} \\ \frac{\partial H}{\partial \lambda_\mu} & \frac{\partial H}{\partial \gamma_h} \end{bmatrix}\right|_{(\lambda^*_{\mu_0},0)} = \begin{bmatrix} \lambda_\mu(1-\lambda_\mu)\left.\frac{\partial \pi_\mu}{\partial \lambda_\mu}\right|_{(\lambda^*_{\mu_0},0)} & \left.\frac{\partial G}{\partial \gamma_h}\right|_{(\lambda^*_{\mu_0},0)} \\ 0 & \kappa\lambda^*_{\mu_0}\omega - (1-\kappa)(\lambda^*_{\mu_0} w_\mu + (1-\lambda^*_{\mu_0})w_\tau) \end{bmatrix}$$

where

$$\left.\frac{\partial \pi_\mu}{\partial \lambda_\mu}\right|_{(\lambda^*_{\mu 0},0)} = \frac{(w_\mu - w_\tau)F}{\lambda^*_{\mu 0} c + (1-\lambda^*_{\mu 0})} > 0.$$

The roots of the characteristic polynomial $f(\epsilon)$ are

$$\begin{aligned}
\epsilon_1 &= \lambda_\mu(1-\lambda_\mu) \left.\frac{\partial \pi_\mu}{\partial \lambda_\mu}\right|_{(\lambda^*_{\mu 0},0)}, \\
\epsilon_2 &= \kappa\lambda^*_{\mu 0}\omega - (1-\kappa)(\lambda^*_{\mu 0} w_\mu + (1-\lambda^*_{\mu 0})w_\tau),
\end{aligned}$$

where $\epsilon_1 > 0$. If (35) is not satisfied, then $\epsilon_2 < 0$. In other case, i.e., if (35) is satisfied, then it is not possible to determine the sing of $\epsilon_2$. Therefore if (35) is not satisfied, then $(\lambda^*_{\mu 0}, 0)$ is saddle, in other case we only now that it is unstable.

## A.6 Steady state $(\lambda_{\mu^*_1}, 1)$

Consider $\lambda_{\mu^*_1}$ as in (45), this steady state does not exist if $\lambda_{\mu^*_1}$ is not positive. If $\lambda_{\mu^*_1} > 0$, then

$$\left.\begin{bmatrix} \frac{\partial G}{\partial \lambda_\mu} & \frac{\partial G}{\partial \gamma_h} \\ \frac{\partial H}{\partial \lambda_\mu} & \frac{\partial H}{\partial \gamma_h} \end{bmatrix}\right|_{(\lambda^*_{\mu 1},1)} = \begin{bmatrix} \lambda_\mu(1-\lambda_\mu) \left.\frac{\partial \pi_\mu}{\partial \lambda_\mu}\right|_{(\lambda^*_{\mu 1},1)} & \left.\frac{\partial G}{\partial \gamma_h}\right|_{(\lambda^*_{\mu 1},1)} \\ 0 & -\kappa\lambda^*_{\mu 1}\omega + (1-\kappa)(\lambda^*_{\mu 1} w_\mu + (1-\lambda^*_{\mu 1})w_\tau) \end{bmatrix}$$

where

$$\left.\frac{\partial \pi_\mu}{\partial \lambda_\mu}\right|_{(\lambda^*_{\mu 1},1)} = \frac{(w_\mu + \omega - w_\tau)F}{\lambda^*_{\mu 1} c\sigma + (1-\lambda^*_{\mu 1})} > 0.$$

The roots of the characteristic polynomial $f(\epsilon)$ are

$$\begin{aligned}
\epsilon_1 &= \lambda_\mu(1-\lambda_\mu) \left.\frac{\partial \pi_\mu}{\partial \lambda_\mu}\right|_{(\lambda^*_{\mu 1},1)}, \\
\epsilon_2 &= -\kappa\lambda^*_{\mu 1}\omega + (1-\kappa)(\lambda^*_{\mu 1} w_\mu + (1-\lambda^*_{\mu 1})w_\tau),
\end{aligned}$$

where $\epsilon_1 > 0$. If (35) is not satisfied, then $\epsilon_2 > 0$. If (35) is satisfied, then it is not possible to determine the sing of $\epsilon_2$. Therefore is if (35) is not satisfied, then $(\lambda^*_{\mu 1}, 1)$ is repeller, in other case we only now that it is unstable.

## A.7 Steady state $(\lambda^*_\mu, \gamma^*_h)$

Consider $\lambda^*_\mu$ and $\gamma^*_h$ as (46) and (47), respectively. In this case

$$\left.\begin{bmatrix} \frac{\partial G}{\partial \lambda_\mu} & \frac{\partial G}{\partial \gamma_h} \\ \frac{\partial H}{\partial \lambda_\mu} & \frac{\partial H}{\partial \gamma_h} \end{bmatrix}\right|_{(\lambda^*_\mu,\gamma^*_h)} = \begin{bmatrix} \lambda_\mu(1-\lambda_\mu) \left.\frac{\partial \pi_\mu}{\partial \lambda_\mu}\right|_{(\lambda^*_\mu,\gamma^*_h)} & \left.\frac{\partial G}{\partial \gamma_h}\right|_{(\lambda^*_\mu,\gamma^*_h)} \\ \gamma^*_h(1-\gamma^*_h)[\kappa\gamma + (1-\kappa)(w_\tau - w_\mu)] & 0 \end{bmatrix}$$

where

$$\begin{aligned}
\left.\frac{\partial \pi_\mu}{\partial \lambda_\mu}\right|_{(\lambda^*_\mu,\gamma^*_h)} &= \frac{(w_\mu + \omega\gamma^* - w_\tau)(w_\mu + \omega\gamma^*)F}{\left[\lambda^*_\mu[(1-\gamma^*)w_\mu c + \gamma^*(w_\mu+\omega)c\sigma] + (w_\mu + \omega\gamma^*)(1-\lambda^*_\mu)\right]} > 0, \\
\gamma^* &= \gamma\big|_{\gamma^*_h} \quad \text{with } \gamma \text{ as in (11).}
\end{aligned}$$

The roots of the characteristic polynomial $f(\epsilon)$ of $A$ as in (48) are

$$\epsilon_{1,2} = \frac{\mathrm{tr}(A) \pm \left((\mathrm{tr}(A))^2 - 4\det(A)\right)^{1/2}}{2}$$

with

$$\mathrm{tr}(A) = \lambda_\mu(1-\lambda_\mu)\left.\frac{\partial \pi_\mu}{\partial \lambda_\mu}\right|_{(\lambda_\mu^*,\gamma_h^*)} > 0.$$

Since $\mathrm{tr}(A) > 0$, then $(\lambda_m u^*, \gamma_h^*)$ is not a stable steady state. Therefore $(\lambda_\mu^*, \gamma_h^*)$ is unstable, but it is not possible to determine their classification.

## B Comparative statics of $\boldsymbol{\lambda_\mu}$ in the steady states

### B.1 Parameter in Table 2

Consider the values of $\lambda_{\mu_0}^*$, $\lambda_{\mu_1}^*$, and $\lambda_\mu^*$, as in (44), (45) and (46), respectively.

*i*) Partial derivatives of $\lambda_\mu$ respect to $\sigma$:

$$\begin{aligned}
\frac{\partial \lambda_{\mu_0}^*}{\partial \sigma} &= 0;\\
\frac{\lambda_{\mu_1}^*}{\partial \sigma} &= \frac{(w_\mu+\omega)c}{(w_\mu+\omega)-w_\tau}\frac{\kappa L}{NF} > 0;\\
\frac{\lambda_\mu^*}{\partial \sigma} &= 0.
\end{aligned}$$

*ii*) Partial derivatives of $\lambda_\mu$ respect to $c$:

$$\begin{aligned}
\frac{\partial \lambda_{\mu_0}^*}{\partial c} &= \frac{w_\mu}{(w_\mu-w_\tau)}\frac{L}{NF} > 0;\\
\frac{\lambda_{\mu_1}^*}{\partial c} &= \frac{(w_\mu+\omega)\sigma}{(w_\mu+\omega)-w_\tau}\frac{\kappa L}{NF} > 0;\\
\frac{\lambda_\mu^*}{\partial c} &= 0.
\end{aligned}$$

*ii*) Partial derivatives of $\lambda_\mu$ respect to $F$:

$$\begin{aligned}
\frac{\partial \lambda_{\mu_0}^*}{\partial F} &= \frac{(w_\tau-w_\mu c)}{(w_\mu-w_\tau)}\frac{L}{NF^2} > 0;\\
\frac{\lambda_{\mu_1}^*}{\partial F} &= \frac{w_\tau-(w_\mu+\omega)c\sigma}{(w_\mu+\omega)-w_\tau}\frac{\kappa L}{NF^2} > 0;\\
\frac{\lambda_\mu^*}{\partial F} &= 0.
\end{aligned}$$

*ii*) Partial derivatives of $\lambda_\mu$ respect to $N$:

$$\begin{aligned}
\frac{\partial \lambda_{\mu_0}^*}{\partial N} &= \frac{(w_\tau-w_\mu c)}{(w_\mu-w_\tau)}\frac{L}{N^2F} > 0;\\
\frac{\lambda_{\mu_1}^*}{\partial N} &= \frac{w_\tau-(w_\mu+\omega)c\sigma}{(w_\mu+\omega)-w_\tau}\frac{\kappa L}{N^2F} > 0;\\
\frac{\lambda_\mu^*}{\partial N} &= 0.
\end{aligned}$$

## B.2 Parameter in Table 3

Consider the values of $\lambda^*_{\mu_0}$, $\lambda^*_{\mu_1}$, and $\lambda^*_{\mu}$, as in (44), (45) and (46), respectively.

*i)* Partial derivatives of $\lambda_\mu$ respect to $L$:

$$\frac{\partial \lambda^*_{\mu_0}}{\partial L} = -\frac{(w_\tau - w_\mu c)}{(w_\mu - w_\tau)}\frac{1}{NF} < 0;$$
$$\frac{\lambda^*_{\mu_1}}{\partial L} = -\frac{w_\tau - (w_\mu + \omega)c\sigma}{(w_\mu + \omega) - w_\tau}\frac{\kappa}{NF} < 0;$$
$$\frac{\lambda^*_{\mu}}{\partial L} = 0.$$

*ii)* Partial derivatives of $\lambda_\mu$ respect to $\kappa$:

$$\frac{\partial \lambda^*_{\mu_0}}{\partial \kappa} = 0;$$
$$\frac{\lambda^*_{\mu_1}}{\partial \kappa} = -\frac{w_\tau - (w_\mu + \omega)c\sigma}{(w_\mu + \omega) - w_\tau}\frac{L}{NF} < 0;$$
$$\frac{\lambda^*_{\mu}}{\partial \kappa} = \frac{-w_\tau}{\kappa\omega - (1-\kappa)(w_\mu - w_\tau)} - \frac{(1-\kappa)w_\tau(w_\mu + \omega - w_\tau)}{\Big(\kappa\omega - (1-\kappa)(w_\mu - w_\tau)\Big)^2} < 0. \quad (*)$$

(*) If $\lambda^*_{\mu_0} > 0$ we need that $\kappa\omega - (1-\kappa)(w_\mu - w_\tau) > 0$, which implies that $\frac{\lambda^*_\mu}{\partial\kappa} < 0$.

*iii)* Partial derivatives of $\lambda_\mu$ respect to $w_\mu$:

$$\frac{\partial \lambda^*_{\mu_0}}{\partial w_\mu} = \frac{-w_\tau\left(1 - (1-c)\frac{L}{NF}\right)}{(w_\mu - w_\tau)^2} > 0 \quad (*);$$
$$\frac{\lambda^*_{\mu_1}}{\partial w_\mu} = \frac{-w_\tau\left(1 - (1-c\sigma)\frac{\kappa L}{NF}\right)}{(w_\mu - w_\tau)^2} > 0 \quad (**);$$
$$\frac{\lambda^*_{\mu}}{\partial w_\mu} = \frac{(1-\kappa)^2 w_\tau}{\Big(\kappa\omega - (1-\kappa)(w_\mu - w_\tau)\Big)^2} > 0.$$

(*) If (43) is satisfies then

$$(1-c)\frac{L}{NF} > \left(1 - \frac{w_\mu c}{w_\tau}\right)\frac{L}{NF} > 1,$$

which implies that $\frac{\partial\lambda^*_{\mu_0}}{\partial w_\mu} > 0$.

(**) If (43) is satisfies then

$$(1-c\sigma)\frac{\kappa L}{NF} > \left(1 - \frac{w_\mu c}{w_\tau}\right)\frac{L}{NF} > 1,$$

which implies that $\frac{\partial\lambda^*_{\mu_1}}{\partial w_\mu} > 0$.

*iii)* Partial derivatives of $\lambda_\mu$ respect to $\omega$:

$$\frac{\partial \lambda^*_{\mu_0}}{\partial \omega} = 0;$$
$$\frac{\lambda^*_{\mu_1}}{\partial \omega} = \frac{-w_\tau\left(1 - (1-c\sigma)\frac{\kappa L}{NF}\right)}{(w_\mu - w_\tau)^2} > 0;$$
$$\frac{\lambda^*_{\mu}}{\partial \omega} = \frac{-(1-\kappa)\kappa w_\tau}{\Big(\kappa\omega - (1-\kappa)(w_\mu - w_\tau)\Big)^2} < 0;$$

## B.3 Parameter of Figures

**Table 4 Values of parameters in Fig. 1 and Fig. 2**

| **Parameter** | Fig. 1-(a) | Fig. 1-(a) | Fig. 2 |
|---|---|---|---|
| $N$ | 300 | | |
| $F$ | 7.6 | | |
| $c$ | 0.8 | | |
| $\sigma$ | 0.61 | | |
| $L$ | 20,000 | | |
| $\kappa$ | 0.7 | 0.8 | 0.65 |
| $w_\tau$ | 1 | | |
| $w_m$ | 1.1 | | |
| $\omega$ | 0.48 | | 0.51 |
| The columns only shows changes of values with respect to Fig. 1-(a) | | | |

**Table 5 Values of parameters in Fig. 4**

| **Parameter** | (a) | (b) | (c) | (d) | (e) |
|---|---|---|---|---|---|
| $N$ | 300 | | | | 312 |
| $F$ | 7.6 | | | 7.89 | |
| $c$ | 0.8 | 0.804 | | | |
| $\sigma$ | 0.61 | | 0.64 | | |
| $L$ | 20,000 | | | | |
| $\kappa$ | 0.7 | | | | |
| $w_\tau$ | 1 | | | | |
| $w_m$ | 1.1 | | | | |
| $\omega$ | 0.48 | | | | |
| The columns only shows changes of values with respect to (a) | | | | | |

**Table 6 Values of parameters in Fig. 5**

| **Parameter** | (a) | (b) | (c) | (d) | (e) |
|---|---|---|---|---|---|
| $N$ | 300 | | | | |
| $F$ | 7.6 | | | | |
| $c$ | 0.8 | | | | |
| $\sigma$ | 0.61 | | | | |
| $L$ | 20,000 | 20,700 | | | |
| $\kappa$ | 0.7 | | | | 0.8 |
| $w_\tau$ | 1 | | | | |
| $w_m$ | 1.1 | | 1.106 | | |
| $\omega$ | 0.48 | | | 0.495 | |
| The columns only shows changes of values with respect to (a) | | | | | |

**Table 7 Values of parameters in Fig. 6**

| **Parameter** | (a) | (b) |
|---|---|---|
| $N$ | 300 | 300 |
| $F$ | 7.6 | **7.53** |
| $c$ | 0.8 | **0.79** |
| $\sigma$ | 0.61 | **0.605** |
| $L$ | 20,000 | **20,100** |
| $\kappa$ | 0.7 | **0.77** |
| $w_T$ | 1 | 1 |
| $w_m$ | 1.1 | **1.11** |
| $\omega$ | 0.48 | **0.49** |

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**The authors declare that they have no conflict of interest.**
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