Vested Interests In a Positive Theory of Stagnation and Growth

Per Krusell[*]
University of Rochester

José-Víctor Ríos-Rull
Federal Reserve Bank of Minneapolis
University of Pennsylvania

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Abstract

We study a positive theory of stagnation and growth aimed at understanding the large variations in growth outcomes across actual economies. The theory points to the fundamental role played by *vested interests* in determining policies which are key to the growth process: some agents seek to prevent the adoption of new technologies. We develop a model of technology adoption, and show how technological innovation may sow the seeds of its own destruction. In particular, we find that the equilibrium is characterized by a long cycle of stagnation and growth. Over this cycle, incumbent innovators have sufficient political influence that new technologies are prohibited, and only as these incumbents are phased out of the economy will new innovation occur. In formalizing our theory we make a methodological contribution by characterizing dynamic voting equilibria when voters must forecast the effects of different current policies on future prices and policy outcomes.

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> *"The political economy of technological change is only dimly understood. To some observers, technological change seems to resemble the human life cycle: the vigor of youth is followed by the caution of maturity and finally the feebleness of old age and the 'climacteric'. ...If we are to understand why the fires of innovation die down, we must propose a model in which technological progress creates the conditions for its own demise."* [Mokyr (1990a); p. 261]

1 Introduction

Motivated by the large variations in medium-and long-run economic performance across countries and within countries over time, we study what we believe is crucial for understanding these observations: the process of technological change. Our approach differs from much of the recent literature on economic growth in that we focus on the socio-political process determining growth-oriented economic policies, rather than on what policies are good per se. The pervasiveness of growth-preventing policies—policies that reduce the incentives for investment and technological innovation—suggests that it is especially important to study policy determination in the context of economic growth. Our way of understanding the existence of such policies rests on a notion of *vested interests*: owners of the currently operated technology try to block the emergence of superior technologies by using the political process.

Our point of view leads to a process of technological change which is fundamentally fragile. The first contribution of this paper is to formalize the idea of vested interests in the context of a model of technological change, and, in particular, to give formal meaning to what was hinted at in our opening quote: the possibility that technological progress itself may sow the seeds of its own destruction, leading to a slower pace of technological change and growth than what is technologically efficient. More precisely, we find that our theory can account for policies which imply very poor growth outcomes, and in particular, for cycles with long periods of stagnation and short periods of innovation and growth. These cycles are driven by the dynamic forces created by, on the one hand, the returns to innovation, and on the other, the counteracting vested interests among those who control the old technologies. The cycle of stagnation and growth is an example of how innovation itself *creates* vested interests and, as a consequence, a long period of technological and economic stagnation.

We build on the vintage human capital model of Chari & Hopenhayn (1991). This setup allows us to study both the process of adoption of new technologies and how it interacts with the distribution of agents across age, skills, and political views. The key economic decision for a consumer in this model is the career choice: he can either choose to work as unskilled throughout his career or to accumulate human capital and become a manager toward the end of his lifetime. The managerial human capital is specific to a technology vintage, and the agent's choice also specifies whether to learn to manage an already existing technology, or to innovate by learning to manage a new and better technology. Innovation requires the agent to be unproductive while learning, whereas learning in a technology where there are already skilled agents gives positive productivity.

The career decisions also affect the consumption streams, so the other aspect of innovation is to shift equilibrium consumption away from current products toward future, cheaper ones. It is in this context natural, then, that managers of current technologies are against innovation, since it shifts demand away from their products and lowers their profits. On the other hand, current workers will favor innovation, since it shifts equilibrium consumption away from the present, hence lowering the prices of current products and therefore raising the purchasing power of the unskilled. We consider a regulatory policy of a simple kind: either innovation is allowed, or it is not. Since the career and technology adoption choices may induce heterogeneity in skills, they will also determine the views in the population on the desirability of the regulatory policy. We describe the political process determining the policy by letting agents vote on the current policy, with a majority rule aggregating individual views into a chosen policy.

We find that the properties of the equilibrium of our model depend critically on the characteristics of the initial distribution of economic agents. There are two possible, and very different, long-run economic outcomes: there can be no regulation, and hence sustained technological innovation and growth, or there may be stagnation. In the outcome with perpetual growth and technology adoption, the distribution of skills is the same each period: two thirds of each cohort accumulates new skills, and the rest work as unskilled throughout their careers. Since all young agents are in favor of growth, and all the older unskilled workers are as well, this makes for a majority of five ninths of the population being in favor of laissez-faire, and this outcome is repeated period after period.

With a different initial skill distribution, it is likely to end up in the stagnation-growth cycle. Initially, with a previous two periods of no new technology adoption, the economy is in its most "backward" state in terms of skill distribution: all agents in of each of the middle-aged and old cohorts have skills, but in the same (old) technology. Due to the payoffs from allowing growth, the young and the middle-aged workers join forces and vote for laissez-faire, allowing a takeoff to begin, with the result that two thirds of the young decide to invest in the new skills. However, next period the new innovators and all of the previously middle-aged agents, who are now managers with vested interests against more innovation and are against growth, make up a five ninths majority to vote it down. One period later, the innovators are still around (now as managers) and their no-to-more-innovation is now supported by the middle-aged, who all learned from the innovators and expect to take over as managers one period later. Together, this group is large enough (again, five ninths) to make up a majority against growth for a second period in a row. After the two periods of innovation, the economy is back in its most backward state, the innovators are gone, and the cycle repeats.

Notice that over the stagnation-growth cycle, those who innovate form a key part of the coalition in favor of regulation against more innovation: they first attract managers of older technologies, then younger agents who learned the new innovation from them. Only as the innovators are phased out will there be enough agents without vested interests to again form a majority for laissez-faire. And even then is a yes-to-growth not obvious, due to all the young disciples of the initial innovators who are still around. The dynamic formation of vested interests after technological innovation is long-lived, and indeed for some parametric cases the economy will never display growth again. Thus, the dependence of technological change and growth on the initial skill distribution may be drastic: the cycle has a third of the potential growth rate, and with perpetual stagnation (when it occurs) there is zero growth.

The role of conflicting interests for policy formation has long been recognized; a recent study can be found in Olson (1982). Its particular importance for issues related to technological change is perhaps less explored. Mokyr (1990a) argues, as did others (see, e.g. Maine (1890) and Landes (1983)), that vested interests among agents specialized in the old technologies may have played an important role in the way the Industrial Revolution developed in Britain and elsewhere in Europe.[1] According to the hypothesis, the British leaders at the time were much more reluctant than leaders elsewhere in Europe to give in to the political demands by all those opposed to the new technologies and to the general changes that were occurring. The argument potentially accounts for Britain's relative success early on as well as for its industrial problems experienced later—the political success of special interest groups once in favor of technological change now prevented further change. Olson (1982) gives further historical accounts of how coalitions of agents have been successful in blocking technological and economic development. Moreover, many modern development economists emphasize the interaction between political and economic forces as key to understanding the development process (see for example Krueger (1990)). Indeed, the list of circumstances in which vested interests have been detrimental to economic growth can be made extensive, since it can arguably include all those cases in which taxes or regulation have precluded technological change from occurring. We would suggest, for example, that

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[1] See also Mokyr (1990b) and Mokyr (1992).

trade barriers, high capital taxes, etc. in many cases played this role. One striking and very concrete example of how the incentives for technological innovation have been substantially reduced is Perú; there, opening a new business has at times been associated with next to prohibitively expensive administrative costs, as described in de Soto (1989). Our model attempts to capture some of the forces that lead to vested interests and, in particular, how these forces can arise naturally as a result of the process of technological innovation. In a context of economic growth, we believe that it may be crucial for understanding the political and economic outcomes that the political heterogeneity is not exogenous, but induced by the growth process itself.

Our paper also makes a methodological contribution. We show how to use politico-economic equilibrium theory in dynamic models where there is voting every period, and where all voters are fully rational. This is difficult, since in order to derive a voter's policy preference, it is in general necessary to predict the equilibrium effects of a change in the current policy on the future path of the economic state variable, and on the future path of policy outcomes. To avoid these complexities, the existing literature has taken one of two routes. The first route has been to consider economies with limited dynamics: if no voter cares about the future *per se*, and if in addition there is no equilibrium feedback from future policies and prices to current prices, then a voter's policy preferences are simple to derive, since forecasting future prices is not necessary. This approach imposes constraints on the set of economies which can be analyzed (e.g., it rules out the standard neoclassical growth model), but it is otherwise fully satisfactory.[2] The second route is to assume that agents are fully rational in their consumption behavior, but not in their voting behavior. In particular, it is possible to improve tractability by assuming that the effects of changing a current policy on future policies are forecast incorrectly by the voter.[3]

Our approach is to tackle the problem upfront. The equilibrium definition includes a law of motion of the economy for each current policy, including those current policies which are not political outcomes. This law of motion, which of course has to be consistent with individual optimization and market clearing, is then used by the voter in predicting the effects of alternative current policies. Because the economy we consider here is quite simple, we are able to obtain analytical results, and indeed it turns out that an important element

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[2] See Persson & Tabellini (1994), Glomm & Ravikumar (1992), Perotti (1993), Saint-Paul & Verdier (1992), and Fernandez & Rogerson (1994) for examples.

[3] For this type of approach, see e.g. Boldrin (1993). Also note that it is possible to avoid technical difficulty by assuming directly that voting takes place at time zero only and over a policy sequence that is constrained somehow, e.g. to tax rates that are constant over time, as is done in Alesina & Rodrik (1994) and in Bertola (1993). For a comparison of politico-economic equilibrium concepts in the context of the standard growth model, see Krusell, Quadrini, & Ríos-Rull (1994b).

of the story we are telling about vested interests involves explaining how changes in current policies imply changes in future policies.

In section 2 we describe a version of the model, and we proceed in the following section to describe stationary equilibria for constant, exogenous policies: one stationary equilibrium with technological innovation and growth, and one without. Section 4 then presents the definition of a political equilibrium. The analysis of political equilibria for our model is contained in section 5. In that context, we show how stagnation, as part of a stagnation/growth cycle or as a permanent phenomenon, does occur in democratic equilibria with fully rational agents. Section 6 concludes with some remarks.

2 The Model

For a theory of vested interests and of how they interact with the process of technological change, we need a model where technology adoption is explicit, and where (at least some) agents develop economic attachments to technologies. We chose to use the vintage human capital framework in Chari & Hopenhayn (1991) since it has these two key features. For a given technology to operate, skill is needed, and skill is costly to accumulate. At any point in time, new and more productive technologies are available to learn about, and technology adoption in the model is thus synonymous with the accumulation of skills specific to these new technologies. The key economic decisions are made in a decentralized way: individuals make decisions to forego current income in order to learn about specific technologies, and the obtained skills allows them to earn higher future income.

The conflict of interest in this setup is apparent. For example, a proposed regulation against the adoption of new technologies will have both supporters, typically agents with attachments to existing technologies, and opponents, for example young, uncommitted agents, who have nothing to lose from technological change.

Our model is not identical to that used in Chari & Hopenhayn (1991). First, we make assumptions so that only one technology will be used in production at any point in time. This is a great simplification compared to the original setup, which at any point in time has a nontrivial distribution of firms using different technologies, and associated technology-specific wages. Second, we make the model more complicated by extending the learning process over time. The original setup uses a 2-period-lived overlapping-generations structure where it takes one period to accumulate skill, whereas in our world agents live for three and accumulate skills for two periods. This complication is necessary in order to avoid trivial outcomes. As a result, the distribution of skills and their technology specificity is quite complex. We therefore make the description of our environment sequentially. We first describe our assumptions informally. Second, we present the formal setup with compact notation. Third and finally, we provide a discussion and motivation for the assumptions.

2.1 An informal description of the economy

Agents live for three periods, and they are endowed with one unit of time per period. There is no population growth. Agents care only about their own consumption, and the utility is linear in consumption at the three dates, with a constant rate of discount, β.

The consumption good can be produced from technologies of different vintages. Technologies are all Cobb-Douglas in skilled and unskilled labor, and differ only in the Hicks-neutral productivity component: a τ periods old technology vintage gives $\gamma > 1$ times more output than a $\tau + 1$ technology, keeping the inputs the same.[4] Technology adoption occurs with explicit, time-consuming accumulation of skills for the given technology. Technologies have to be adopted "in order": a new technology can only be a factor γ better than the best existing technology.

The skill accumulation process is key in our model. It specifies who qualifies as skilled and unskilled for any given technology. First, any agent can use his time unit to work as unskilled in any technology. However, unskilled labor is only productive if skilled agents work in the technology (this follows from the Cobb-Douglas assumption).

Skill in a given technology can be obtained either by developing a new technology—"innovating"—or by being an "apprentice" and learn in a technology where there are already skilled agents. Innovation requires two periods of learning, so that the agent becomes skilled in his third period of life. The second way of learning can happen in two ways. First, the agent can be a working apprentice of existing skilled agents for two consecutive periods *in the same technology*, enabling him to work as skilled in this technology in the third period of life. During the apprentice period, the apprentice is also counted as unskilled labor input, and thus contributes to current output. The second way to learn from already skilled agents is to do it only in the second period of life (fast learning), but without being able to qualify as labor input in that period, and thus without contributing to current output. This kind of career is like a costly retraining option: it allows the agent to work as unskilled when young in some technology, switch and learn another technology as middle-aged at the cost of being improductive that period, and then qualify as skilled in that technology as old.

Clearly, the agents' past skill accumulation decisions are crucial for the economy's present and future production possibilities. At the beginning of each period before current decisions

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[4] The functional forms we have chosen simplify the analysis but are not necessary for the main result. What is important is that there be a sufficient amount of complementarity between the two types of labor.

have been made, these production possibilities can thus be summarized by a skill distribution specifying the existing technology-specific skills in the population. This distribution and its dynamic evolution are at the heart of our model.

Finally, there is a "government" with two available regulatory options: either it regulates, or it does not. Regulation means that young agents are not allowed to develop the innovation technology, or, equivalently, that if they do, they are not allowed to operate this technology two periods hence. Retroactive laws forbidding new technologies are not considered, so that any technology that has already been developed can be operated in the present. We assume that there is a universal vote on current regulation each period: each agent casts one vote, and the majority wins.

2.2 A formal description of the economy

We now provide a compact mathematical representation of the assumptions above.

Preferences: $c_1 + \beta c_2 + \beta^2 c_3$, where c_i is the consumption of an agent at age i.

Technologies: Vintages are indexed with τ, with the normalization that $\tau = 0$ is the youngest available technology at the beginning of any period. In equilibrium, $\tau \leq 2$.

Production: $f_\tau(\varphi_s, \varphi_u) = A_\tau \varphi_s^\alpha \varphi_u^{1-\alpha}$, with $0 < \alpha < 1$, where φ_s and φ_u are the inputs of skilled and unskilled labor, and A_τ is the productivity index of vintage τ: $A_\tau / A_{\tau+1} = \gamma$.

Agent types: $x = 1$ for young agents, $x = (2, \tau)$ and $x = (3, \tau)$ for middle-aged and old, respectively, with experience in vintage τ, and $x = 3$ for old without skills. The skill distribution is a measure μ: μ_x is the mass of agents of type x. Note that $\mu_1 = 1$, $\sum_\tau \mu_{2,\tau} = 1$, and $\mu_3 + \sum_\tau \mu_{3,\tau} = 1$.

Government Policies: We use π to denote policies, with $\pi = 0$ meaning that new technologies can be adopted, and $\pi = 1$ meaning they cannot.

Agent choices: $y = (y_a, y_\tau)$. $y_a \in \{s, u, d\}$, where s and u reflect choices to work as skilled and unskilled labor, respectively, and d to learn without current productivity (developing or fast learning). $y_\tau \in \{0, 1, \ldots\}$ is the corresponding technology attachment. The choice y is constrained by the agent's state, x, the policy, π, and the aggregate state, μ: $y \in \Gamma(x, \pi, \mu)$.[5]

Aggregate Activity Measures: φ denotes measures of agents over specific activities: $\varphi_{s,\tau}$ is the measure of agents that work as skilled in technology τ, $\varphi_{x,u,\tau}$ is the measure of unskilled labor of type x in τ, and $\varphi_{x,d,\tau}$ the measure of developers/fast learners of type x in τ. Total

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[5] For example, if $x \neq (3, \tau)$ for some τ, i.e. if the agent has no skill, then $y_a \neq s$, and so no.

unskilled labor input in τ, $\varphi_{u,\tau}$, is thus $\sum_x \varphi_{x,u,\tau}$. In the decentralization below, we will identify skilled agents with "managers", m, and unskilled agents with "workers", n, so we will use $\varphi_{s,\tau} = \varphi_{m,\tau}$ and $\varphi_{u,\tau} = \varphi_{n,\tau}$.

Laws of Motion of States: An agent's state x and current choice y determine the agent's future state x'. We write $x' = \xi(x, y)$; for example, if $x = 1$ and $y = (u, \tau)$, then $x' = (2, \tau')$, with $\tau' = \tau + 1$ if there has been growth (so that the best technology in production tomorrow is better than today's), and $\tau' = \tau$ if there has not.[6]

The aggregate law of motion of the skill distribution μ is purely based on accounting for agents' activity choices: $\mu'_{2,\tau+1} = \varphi_{1,d,\tau} + \varphi_{1,u,\tau}$; $\mu'_{3,\tau+1} = \sum_{x:i=2} \varphi_{x,d,\tau} + \varphi_{(2,\tau),u,\tau}$; and $\mu'_3 = 1 - \sum_\tau \mu'_{3,\tau}$. If there is growth, the same formulas apply but with the $\tau + 1$ indices replaced by τ's. With this, the description of the economic environment is complete.

2.3 Discussion of assumptions

There are two reasons why we assume that agents live for three periods. First and most importantly, if agents live for only two periods and there is no population growth, at least half of the population—the young agents—will always be in favor of technological change. Without arbitrary restrictions on voting rights among economically active agents, this means that there will typically be an absolute majority for this regulatory option (old agents without advanced skills will prefer technological change as well). This makes the formation of vested interests trivial; in particular, there is no interesting interaction between technological change and vested interests. With population changes the outcome could be different, but any interesting changes in policies would then be trivially predicted by population change alone. Second, tied election results between young and old cannot occur with a group of middle-aged present. Indeed the middle-aged are pivotal to election outcomes in this model, and their views are always a nontrivial outcome. In the context of the population structure it should also be said that if we made agents live for more than three periods, the accumulation of vested interests becomes even more important for policy decisions and technological change. In other words, in order to be able to analyze our main question in a meaningful way, we need to allow a *minimum* of two periods of learning, and we selected to study the simplest case.

We added the fast learning option to avoid technological regress as an equilibrium outcome, and this assumption is not necessary for the rest of the results.[7]

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[6] Note that this renormalization of technologies formally requires ξ also to be a function of φ; we leave this argument out, however, for reasons of notational simplicity.

[7] If the option is ruled out, the equilibria we report below are the same, *except* in that whenever an

The assumption that regulation can only take two values is a simplification in several ways (an alternative would have been more general, technology-specific taxes). First, it makes the aggegation of political preferences very simple, allowing us to focus instead on the dynamics of the voting outcome. Second, it makes it much easier to derive the evolution of the skill distribution, since a large part of the mechanics of the skill evolution is now a direct function of whether innovation is or is not allowed.

3 Equilibria for a Given Policy Choice

We now turn to describing equilibria for this environment. We adopt a recursive, first-order Markov equilibrium definition: equilibrium prices and quantities are functions of the current state of the economy.[8] In this section we treat the regulatory policy as being given exogenously as a function of the state of the economy: $\pi = \Psi(\mu)$. After defining equilibria we characterize the set of steady states associated with constant policies over time. These steady states have a stationary skill distribution.

The decentralization we employ is the following: managers (skilled agents) hire workers (unskilled agents) at competitive (marginal-productivity) wages and become residual claimants to output. Wages are thus technology-specific; a young agent may choose to work at a lower current wage in order to accumulate a skill that allows a higher future wage. Agents choose their activities based on the available earnings prospects, and in equilibrium two agents in the same cohort with different careers have to earn the same life-time income.[9]

We start by noting that the aggregate state of the economy is given by μ, the distribution of agents across types. The individual state also includes x, the agent's own type. We now describe the problem of a generic young or middle-aged agent:

The Young or Middle-Aged Consumer's Problem

$$\begin{aligned} v(x,\mu) &= \max_{y} \{W(y,\varphi)/P(\varphi) + \beta v(x',\mu')\} \text{ s.t.} \\ y &\in \Gamma(x,\pi,\mu) \\ x' &= \xi(x,y) \\ \mu' &= h_{\mu}(\mu) \end{aligned} \tag{1}$$

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agent had chosen fast learning and switched from a $\tau+1$ periods to a τ periods old vintage in the current equilibrium, he would now stay and become skilled in the older technology.

[8] The focus on first-order equilibria is made for analytical and computational convenience, but we are not aware of the existence of other equilibria.

[9] Thus, the reason why one should not in general expect only one prevailing wage is that the decision to work has two components: the current contribution to output, and the learning.

$$\begin{aligned}\varphi &= h_\varphi(\mu)\\ \pi &= \Psi(\mu).\end{aligned}$$

Here, v is the value function in this dynamic programming problem, and y is the agent's current choice given a value of his state, x, and the aggregate state μ. The maximizing choice for y is labeled $g(x,\mu)$. Note that in models with finitely-lived agents like the one here, the age component of x restricts the value functions to be zero for ages outside the life span of agents.

The function W is the wage of an agent that takes action y when the aggregate choices are φ, while P is the price of the good. The normalization we use is to set the value of unskilled labor of vintage $\tau = 1$ equal to 1, so that $W((u,1),\varphi) = 1$ for all $\varphi \in \Phi$. Note that $W((d,\tau),\varphi) = 0$, for all τ, and that the assumption of perfect competition completely determines all other prices: $W(u,\tau,\varphi) = \frac{\varphi_{m,\tau}^{\alpha}\varphi_{n,\tau}^{-\alpha}\gamma^{1-\tau}}{\varphi_{m,1}^{\alpha}\varphi_{n,1}^{-\alpha}}$, and $P(\varphi) = (\frac{\varphi_{n,1}}{\varphi_{m,1}})^{\alpha}(1-\alpha)^{-1}$. Note already at this point, however, that the dependence of W on technology will not be an issue in the equilibria will look at below, since there will only be one type of technology in production at any point in time, and thus only one (positive) wage.

The agent is fully aware of the way the future skill distributions, aggregate choices, and policy outcomes depend on the current distribution. This is captured by the functions $h \equiv (h_\mu, h_\varphi)$, and Ψ: $h_\mu(\mu)$ gives tomorrow's skill distribution as a function of today's, and $h_\varphi(\mu)$ gives today's aggregate choices as a function of the current state.

Next, we have to characterize the problem of the old agent. His options depend on his type. If his type is 3, i.e. he is unskilled, the problem is just:

$$v(3,\mu) \equiv \max_{\tau}\ W((u,\tau),\varphi)/P(\varphi)$$

If the old agent has managerial skill he can choose to become a manager in the technology he has expertise in or to work as unskilled. The utility derived from becoming a manager is given by the profits, in units of unskilled labor, associated to this activity. The profits are given by:

$$R(\tau,\varphi) \equiv \max_{l}\ \left\{P(\varphi)\gamma^{1-\tau}l^{1-\alpha} - W((u,\tau),\varphi)\, l\right\}.$$

The utility of an old agent of type $(3,\tau)$ is then the maximum between the one obtained as a manager and the highest one obtained as unskilled:

$$v((3,\tau),\mu) = \max\ \{R(\tau,\varphi)/P(\varphi)\ ,\ v(3,\mu)\}\,.$$

We also use the function $g(x,\mu)$ to denote the activity and the technology that solves the old agent's problem. We will furthermore use $l(\tau, \mu)$ to denote the aggregate demand for unskilled labor in technology τ. This completely determines the problem of all agents now we are ready to define an equilibrium for a given policy Ψ.

Definition 1 *An equilibrium given policy choice Ψ is a set of functions v, g, h, W, P, and l with the following properties*

(i) (v, g) solves the agents' problems.

(ii) The consumers' choices g generate h_{φ}.

(iii) The aggregate choices h_{φ} generate h_{μ}.

(iv) The price functions, W and P, are competitively determined.

(v) The market for unskilled labor clears: $l(\tau, \mu) = h_{\varphi_{n\tau}}(\mu) = \varphi_{n\tau}$.

Condition *(i)* requires agent maximization. The standard recursive equilibrium condition requiring individual choices to be consistent with the given aggregate laws of motions is spelled out in conditions *(ii)* and *(iii)*. Condition *(iv)* requires competitive pricing, and condition *(v)* is a standard market-clearing requirement.

We now study our economy in the case where the policy is exogenous and constant over time. If there is regulation this means that there will be no technological innovation at all. We label the resulting state the "stagnation" steady state. If innovation is allowed, the economy will under certain conditions grow indefinitely, experiencing innovation each period: the growth steady state. In the next two subsections we will characterize each of these two cases.

3.1 The Stagnation Steady State

We first treat the case of $\pi = 1$, i.e. $\Phi(\mu) = 1$ for all μ: the case when the adoption of new technologies is not allowed in any state. This situation of perpetual stagnation could also be referred to as a "medieval" equilibrium, since it involves no innovation, and hence no growth, and the existence of "apprentices" and "masters". We conjecture the precise form of a stationary equilibrium and proceed to verify the conjecture and to show that the conjectured stationary equilibrium is unique.

In particular, we conjecture that there is only one technology in operation and all agents hence make the same choices in the first two periods. With a production technology such that $\alpha \geq \frac{1}{3}$, all agents become masters ($\varphi_m = 1$), while if $\alpha < \frac{1}{3}$, only a fraction $\varphi_m < 1$ become masters and the rest workers.

The price for the good associated with the conjectured equilibrium is

$$P = \left(\frac{3-\varphi_m}{\varphi_m}\right)^{\alpha} \frac{1}{1-\alpha}$$

while the earnings for a manager, R, are

$$R = \frac{\alpha}{1-\alpha}\frac{3-\varphi_m}{\varphi_m}$$

so that $\varphi_m \leq 1$ implies that the manager's earnings are higher than those of a worker if and only if $\alpha \leq \frac{1}{3}$. We hence find that the fraction φ_m has to equal 1 if $\alpha \geq \frac{1}{3}$ and that if $\alpha < \frac{1}{3}$, then $\varphi_m = 3\alpha$ and the master's earnings are the same as those of the worker/apprentice.

Are these prices consistent with the conjectured outcomes? The dynamic programming problem can be solved backward in this case, since the agents have a finite time horizon. As furthermore the option of opening up new technologies is not available, there is only one technology to go to. The managerial decision is trivial in the third period and our prices guarantee that the proposed φ_m is consistent with optimization. We have

Proposition 1 *When $\Psi(\mu) = 1$ for all μ, there is a unique stationary equilibrium with one technology in operation. In this equilibrium all agents become managers if $\alpha > \frac{1}{3}$, and a fraction $\varphi_m = 3\alpha$ otherwise.*

PROOF: Existence is guaranteed by the above arguments. The argument for uniqueness relies on stationarity of the skill distribution and on the fact that the career paths in the two technologies could not give the same life-time earnings if their total-factor productivities differ. In order to use this argument formally, we first need to show that there cannot be switching between two technologies. To see this, note that agents who switch always pick the highest spot wage rate, so if there is switching between two technologies, these technologies have to have the same wage rate. But if they do, then masters' rents also have to be equal: if not, then a master career in one of the technologies would give higher total payoff than in the other. But with both wage rates equal in the two technologies, the input ratios also have to be equal, which is impossible since total-factor productivities differ across the technologies.

Now given that there is no switching, stationarity implies that with more than one technology in operation it would have to be true that input ratios are the same across these technologies. This, however, would imply that wages and masters' rents are different in different technologies, since total-factor productivities differ across technologies. In particular, the highest productivity technology would have uniformly higher earnings, violating the assumption that not all agents are in one technology. Hence we conclude that only one technology can be operated in a stationary equilibrium without growth. □

3.2 The Growth Steady State

We now turn to the analysis of the case when innovation is assumed to be allowed in every period: $\pi = 0$. We will focus on the simplest kind of stationary equilibrium with growth, namely one where there is only one technology currently in operation, and two under development. We describe our proposed equilibrium and show the conditions on primitives under which all equilibrium conditions are met. We have not characterized or proved existence of stationary equilibria for other parameter values. Such values may imply stationary distributions with more than one technology in operation.

The stationary equilibrium we construct has a fraction $\bar{y}$ of the young choosing to develop new technologies. The remainder of the agents work in the only technology under operation and hence switch twice during their life-time. No other actions are taken. In this equilibrium, earnings profiles have to be such that young agents are indifferent between managerial and working careers, so that $1 + \beta\gamma + (\beta\gamma)^2 = (\beta\gamma)^2 R$. Similarly to the steady state without growth, $R = \frac{\alpha}{1-\alpha}\frac{3(1-\bar{y})}{\bar{y}}$, which allows us to solve for $\bar{y}$. We can thus formulate:

Proposition 2 *When $\Psi(\mu) = 0$ for all μ, there is a set of parameter values (β, γ, α) of nonzero measure for which there exists a stationary equilibrium with one technology in operation and two under development. In this equilibrium, $\varphi_{31} = \varphi_{2d} = \varphi_{1d} = \bar{y}$, and $\varphi_{n1} = 3(1-\bar{y})$, where $\bar{y} = \frac{1}{1+\frac{1+\beta\gamma+(\beta\gamma)^2}{\beta\gamma}\frac{1-\alpha}{3\alpha}}$.*

PROOF: We proceed by verifying that all agents maximize. We start with old workers. It is obvious that the switchers cannot do better, as any other alternative involves zero consumption. The managers could choose to become workers; however, the condition on indifference between careers implies $R > 1$ (so long as $\beta\gamma > 0$), so they choose to manage. The same argument applies to middle-aged workers who have been developing the newer technologies. The middle-aged who worked as young could decide not to switch, and instead study their technology for one period on their own and then attract workers and manage this technology the next period. In fact, better still, these agents can retrain in the currently best technology in production, and later become managers for this technology. This would give a life-time income which is dominated by switching if

$$1 + \beta^2 \max_l \left\{\gamma l^{1-\alpha} - \gamma^2 l\right\} \leq \left(1 + \beta\gamma + (\beta\gamma)^2\right).$$

It only remains to show that no other activity than to develop technology -1 or to work are chosen by the young. The inequality derived above ensures that it does not pay to go into technology 1, and technologies 2, 3, etc. are clearly worse still. What about technology 0, which is already under development by the current middle-aged? Using it would pay $\beta\gamma$ in the second period, because then the agent would be working. It would, however, give a lower return in the last period. To rule out that the alternative strategy gives higher life-time utility, it has to be that

$$\beta\gamma + \beta^2 \max_l \left\{ \gamma l^{1-\alpha} - \gamma^2 l \right\} \leq \left(1 + \beta\gamma + (\beta\gamma)^2\right).$$

The inequalities above can be expressed purely in terms of parameters of the economy. If they are met, we are assured that the proposed behavior is indeed optimal. These inequalities are non-trivial restrictions on the parameter space. However, they define a set of parameter values which is of nonzero measure. □

4 Political Equilibrium: A Formal Treatment

We now need to discuss the political aspects of our dynamic economy: the determination of Ψ by aggregating the individuals' views about the policy parameter. One of the key contributions of our paper is to develop the formal language necessary for analyzing dynamic political equilibria where policies are voted over in each period and where the political participants are fully rational. This is the aim of the present section. The equilibrium definition we adopt is quite general. In particular, it can be applied to fully dynamic setups such as the infinitely-lived agent growth model.[10] In the next section, we put our equilibrium definition to use in our simple technology-adoption economy.

Agents in our economy have two roles: they are consumers and they are participants in the political process. The consumer behaves as in the competitive equilibrium described in the previous section. The political participant forms preferences over current policies. In particular, he thinks about what alternative current policies will imply for his utility, taking into account how these policies will affect current and future prices. An important part of this is to figure out how future political decisions are affected, since future policies feed back on current decisions and prices. This effect will turn out to be crucial: in our economy, today's political decisions critically change the properties of future voters and therefore change future votes.

We will refer to Ψ as the policy outcome function. We formally derive political preferences over the current policy alternatives by having the agent evaluate his utility under the equilibrium paths implied by each possible current policy. To calculate an equilibrium path for a given policy today, the agent takes next period's actions and political outcome to be given by those implied by the equilibrium functions. A voter's political choice is then a

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[10] Elsewhere (Krusell & Ríos-Rull (1994) and Krusell, Quadrini, & Ríos-Rull (1994a)), we apply our equilibrium definition in a positive quantitative analysis of capital taxation. That setup is more complex, however, and we need to use numerical techniques to characterize equilibria.

current policy that maximizes his political preferences.[11]

The key mechanism that has to be added to our notion of a political equilibrium is a condition that delivers the Ψ function from first principles. In order to do this, we have to construct a procedure that allows the agent to evaluate his utility under different policies.

First, if the current policy is $\pi = \Psi(\mu)$, the agent will know how to evaluate his utility: it is then simply given by $v(x, \mu)$ in Definition 1 above. Second, for a different policy, $\pi \neq \Psi(\mu)$, the calculation is more difficult: it is necessary to find the equilibrium response to a changed policy. This can be thought of as a one-period deviation from the policy rule Ψ. Therefore, let the function $H(\mu, \pi) \equiv (H_\mu(\mu, \pi), H_\varphi(\mu, \pi))$ be the law of motion of the aggregate state and the aggregate choices for a situation where today's policy is an arbitrary π—which does not have to equal $\Psi(\mu)$—and tomorrow's aggregate choices and policy are given by the original functions h and Ψ.[12] The problem of the agents can be written compactly in this case if we interpret the function W to also include the returns to managerial activities as:

$$\begin{aligned} V(x, \mu, \pi) &= \max_y \{W(y, \varphi)/P(\varphi) + \beta\, v(x', \mu')\} \text{ s.t.} \\ y &\in \Gamma(x, \pi) \\ x' &= \xi(x, y) \\ \mu' &= H_\mu(\mu, \pi) \\ \varphi &= H_\varphi(\mu, \pi) \end{aligned} \tag{2}$$

The decision rule that solves this problem is denoted $G(x, \mu, \pi)$. The utility attained for the alternative policy is labeled $V(x, \mu, \pi)$. It is key to note in this maximization problem that tomorrow's value is given by v: this problem evaluates the utility associated to having a one-period departure from the policy specified by Ψ. We take it as given in (2) that v satisfies the Definition 1, so that $v(x, \mu) = V(x, \mu, \Psi(\mu))$, $g(x, \mu) = G(x, \mu, \Psi(\mu))$, and $h(\mu) = H(\mu, \Psi(\mu))$: a one-period alternative choice of policy π generates the laws of motion under no deviation if $\pi = \Psi(\mu)$. Lastly, $L(\tau, \mu, \pi)$ is now the aggregate demand for unskilled labor.

We denote by $\psi(x, \mu)$ the most preferred political outcome of an agent with individual state x when the aggregate state is μ:

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[11] We describe decision rules by functions. This should be interpreted as a selection from the set of maximizing choices, if this set is not a singleton. Our economy of the previous sections does not produce unique choices generally (young agents may be indifferent between careers or policies), and we use functions only for notational convenience.

[12] Our convention is thus to use capital letters for the equilibrium value functions and laws of motion in the one-period deviations.

$$\psi(x,\mu) \equiv \arg\max_{\pi} \; V(x,\mu,\pi) \tag{3}$$

Here as well, we assume for expositional simplicity that there are no ties.

Individual preferences can be aggregated into a political outcome. We use majority rule to aggregate those preferences:

$$\Psi(\mu) = \arg \max_{\pi \in \{0,1\}} \int_{x:\psi(x,\mu)=\pi} \mu(dx). \tag{4}$$

The stage is now set with all the required ingredients for a definition of equilibrium. We have well-defined behavior for given policies, and, given behavioral rules, we have well-defined preferences over such policies. Furthermore, we have a political aggregator or political process that uses these preferences to select an outcome. At this point, it should be obvious that our notion of equilibrium includes a policy outcome function that, when taken as given, generates preferences over policies that, when aggregated, in turn reproduces the given policy outcome function. The political equilibrium can therefore be formally defined as follows:

Definition 2 *A political equilibrium is a set of functions V, G, H, W, P, L, ψ, and Ψ with the following properties*

(i) (V, G) solves (2).

(ii) The consumers' choices G generate H_{φ}.

(iii) The aggregate choices H_{φ} generate H_{μ}.

(iv) The price functions, W and P, are competitively determined.

(v) The market for unskilled labor clears: $L(\tau,\mu,\pi) = H_{\varphi_{n\tau}}(\mu,\pi) = \varphi_{n\tau}$.

(v) ψ and Ψ are given by (3) and (4), respectively.

Conditions *(i)-(v)* are parallel to *(i)-(v)* of Definition 1, extended to include the behavior under the larger set of paths. Condition *(vi)* describes both the forming of political preferences and its aggregation through majority rule.

The political mechanism used in the definition was majority rule, but other political mechanisms can be used as well, e.g. income- or age/type-weighted voting. In particular, we think of a political aggregator function as a function A such that $\Psi(\mu) = A(\psi,\mu)$. It is easy to see that majority rule is a specific function A.

5 The Political Economy of Stagnation and Growth

Our first task is now to clarify the sources of political disagreement. We do this in subsection 5.1, where we also discuss on a preliminary level the plausibility as political outcomes of the two types of steady states from sections 3.1-3.2. We then simplify our economy to one with a finite number of agents in the following sections and proceed to formally characterize and prove existence of political equilibria.

5.1 Political Disagreement: Preliminary Discussion

We turn now to addressing the issue of what agents prefer within the context of the two steady states characterized above. To highlight the role of vested interests in our model, note that in the case where there is only one technology in operation the equilibrium prices will satisfy

$$R(\varphi) = \frac{\varphi_n}{\varphi_m}\frac{\alpha}{1-\alpha}$$

$$P(\varphi) = \left(\frac{\varphi_n}{\varphi_m}\right)^{\alpha}\frac{1}{1-\alpha}$$

which are both given in terms of the numéraire (units of unskilled labor). We therefore have

$$\text{Current payoff for a manager } = R/P = \alpha\left(\frac{\varphi_n}{\varphi_m}\right)^{1-\alpha}$$

$$\text{Current payoff for a worker} = 1/P = (1-\alpha)\left(\frac{\varphi_n}{\varphi_m}\right)^{-\alpha}.$$

Observe that as the number of young workers increases, the general equilibrium result is that the consumption level for the current product increases. When the young innovate, they effectively also choose future over present products. So as the number of young innovators rises, the demand for current products goes down, as represented, then, by a decrease in φ_n. Note furthermore that R/P is increasing in φ_n and that $1/P$ is decreasing in φ_n, so with innovation, the payoff of managers goes down and the payoff of workers goes up. In short, managers are worse off with innovation, since it shifts demand toward future products, resulting in lower equilibrium profits; and workers are better off with innovation, since the worker's purchasing power goes up—the innovation of future products makes the demand, and hence the price, for the current product go down in equilibrium.[13]

We now use the simple characterization above in order to discuss informally the political

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[13] There is an alternative way, using labor market interactions, to describe why there are vested interests in this framework. The argument rests on noting that managers and unskilled workers are complements in production, whereas unskilled workers are perfect substitutes for each other. Since innovation decreases the number of unskilled workers, managers will therefore favor $\pi = 1$: it increases their marginal product. Workers, on the other hand, favor $\pi = 0$ because innovation increases their marginal productivity by decreasing the size of the labor force.

aspects of the two steady states. When there is perpetual growth, there are five groups in distinct situations: young agents, and middle-aged and old with managerial or working careers. First, everything else given, young agents will always prefer growth, since it makes higher-productivity technologies—cheaper products—available. Of course, and this is an inherent difficulty in our setup and a key reason for our need of a formal treatment, "everything else given" is an important condition: the choice of policy today may affect tomorrow's policy, since it changes the skill distribution in the electorate. Second, agents on a managerial career path either develop a new technology (the middle-aged) or are ready to manage a firm (the old). Since the payoff of these agents is the current and future managerial profits and the above arguments imply that innovation today will shift demand (equilibrium consumption) toward the products produced two periods hence and consequently lower this payoff, these agents will be against innovation. Third, working agents, both middle-aged and old, prefer growth: these agents' purchasing power increases if there is innovation, since innovation shifts equilibrium consumption toward future products with an accompanying decrease in the price of current and next period's products. The relative sizes of the five groups are the key to the policy outcome. In particular, the measure of the group in favor of growth will be $1 + (1 - \varphi_n) + (1 - \varphi_n) = 3 - 2\varphi_n$, and that of the group against is $\varphi_n + \varphi_n = 2\varphi_n$. If the primitives are such that $\varphi_n < \frac{3}{4}$, then growth seems possible as a self-generating outcome of our dynamic political process.

Turning to the no-growth steady state, there are really only three distinct groups: young, middle-aged, and old (assuming, for simplicity, that all old agents become managers). As before, young prefer growth. Old agents prefer not to have growth, for the same reason as in the steady state with growth: innovation comes hand-in-hand with lower equilibrium consumption of the present product, and hence lower equilibrium profits. Finally, middle-aged agents in this case have a harder political decision since their career involves both working at a salary as unskilled and earning a manager's rent in their third period of life. If some young become innovators, and hence lower the current demand for products, the middle-aged agents can enjoy lower product prices in the current period. At the same time, these same agents face lower future profits as managers, since current innovation also competes with the product they will sell in the next period. What, then, do the middle-aged prefer?

The decision making process of the middle-aged in the no-growth situation illustrates the difficult aspect of analyzing dynamic voting models: it requires the ability to predict the future path of the economy under both policies today, and this in turn requires the ability to predict associated future policies, so that the relevant prices (P, P' and R') can be calculated. These prices depend on current and future behavior, as well as on the vote in future periods. With our equilibrium definition above, we choose to tackle this problem upfront. In the next section we show how equilibria can be characterized for a version of our economy with a finite number of agents in each generation.

5.2 Characterization of Equilibria

As should now be clear from earlier sections, nontrivial dynamic political-equilibrium models where agents are fully rational have a fundamental property which makes equilibrium characterization difficult: out-of-steady-state behavior always needs to be analyzed. It is furthermore well known that the difficulty of characterizing dynamics increases very rapidly in the size of the state space. In our economy the distribution of skills across agents is our state variable, and in order to obtain analytical results, we therefore limit our discussion to economies with a finite number of agents.

We therefore study the simplest interesting case: we assume that there are three agents per cohort.[14] This allows us to focus on a relatively small set of values for μ, thereby obtaining 23 different states, most of which are transient. Furthermore, we are interested in restricting the parameter vector (β, α, γ) so that the steady states of sections 3.1 and 3.2 exist as economic equilibria, and so that the remaining economic and political conditions of our equilibrium definition can be met as well. Our strategy of characterization is by construction, and it works as follows. Since both consumers and voters face maximization problems over discrete choice sets, the equilibrium conditions have the form of a set of inequalities. We selected two specific parameter vectors, constructed equilibria for each, and then verified that there is an open set of parameter vectors around each of the given vectors where the equilibrium does not change in fundamental character.[15] The latter verification is straightforward since we are typically dealing only with nonbinding inequality constraints.[16]

The two parameter vectors were selected to show, first, that our focal stagnation-and-growth equilibrium exists for a wide range of parameter values, and second, that perpetual

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[14] The reason for the number three, again, is minumum complexity. First, one agent per generation is too little, since that would not allow perpetual growth (there would be no workers present); indeed the only way to have positive production in such an economy would be to have skip innovation in some periods, thus introducing a tradeoff which would make the effect of politics alone less transparent. With two agents per generations there would be ties in votes in many situations, and we did not want our results to be driven by arbitrary tiebreaking rules.

[15] It is possible to provide global conditions, but we chose not to present such conditions here since they are tedious to state and not particularly transparent.

[16] The finite number of agents and the fact that the career choice is discrete make it necessary to use a lottery implementation. In particular, we consider a "planner" for each generation who selects the number of young agents to innovate, and individual activities are then assigned randomly.

stagnation is only possible for some parameter configurations, and then in addition to the stagnation-and-growth equilibrium.

Some aspects of the description of equilibrium are somewhat complex, and our presentation starts out with a statement of the main result and a discussion of the key equilibrium charateristics. We thereafter go into the detail of how the equilibrium works. We first support the political behavior of the agents in a series of characterizations beginning with the ergodic set of states, and then turning to the set of transient states. The economic behavior of the agents involves a set of inequality constraints, which for the most part are trivial to verify. We do not include proofs for all our claims in this respect, but a complete list of arguments can be obtained from the authors.

5.2.1 The Main Result

We define economy 1 as given by an open set of parameter values around the vector given by $(\alpha, \beta, \gamma) = (0.8, 1.2, 2.2)$. Similarly, economy 2 refers to an open set of parameter values around $\alpha = 0.8$, $\beta = 0.4$, and $\gamma = 3.6$. The two parameter vectors are chosen so that a model period corresponds to 25 years, implying yearly discount rates β of 1.01 and 0.96, respectively.[17] The corresponding values for the yearly growth potential, γ, are 1.03, and 1.05, which also seem reasonable given the data.[18]

Our main result is:

Theorem 1 *For economies 1 and 2, there exists an equilibrium with the following properties:*
(1) There is a set of 23 states which the economy will never leave and each of which has only one technology in production.
(2) Agents who develop new technologies never work as unskilled.
(3) With the exception of young agents, agents with the same age and skill always choose the same activity.
(4) There are 2 ergodic sets: one with a unique element and perpetual growth ($\pi = 0$), and one 3-period cycle with two periods of stagnation ($\pi = 1$) and one period of growth.
(5) The other 19 states are transient: 9 lead to the state of perpetual growth, and the remaining 10 lead to the stagnation-growth cycle.

Figure 1 below summarizes the mechanics of our recursive political equilibrium.

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[17] These values are representative for the values used in the empirical overlapping generations literature (see Ríos-Rull (1992) for a discussion).

[18] If a period were taken to mean 15 years, we would get $\beta \in \{1.01, 0.94\}$, and $\gamma \in \{1.05, 1.09\}$.

Figure 1

The key parts of the equilibrium can be completely described with 6 of the 23 states. The states in the figure are labeled according to a listing of the 23 states, which is described in Table 1 in the back. States in which innovation is not allowed are crossed. State 17 is the state with perpetual growth; the cycle consists of states 18, 3, and 21. The political aspects of the equilibrium are indicated by the dotted arrows: state 18 allows innovation and leads to state 3, but had the vote been against innovation the economy would have stayed in state 18, as indicated by the dotted arrow. Similarly, state 17 would have led to state 23 with a no-vote, and thereafter to the cycle, but the equilibrium outcome given state 17 is to remain in that state. States 11 and 23 are transitory, but are needed in a full description of the equilibrium: the political consideration requires that we look at where the economy is heading for a policy that disagrees with the majority choice. For example, showing that 17 is a steady state involves much more than what was done in section 3.2—it involves verifying all the aspects of Figure 1.

In the following subsections we will make more precise the nature of the equilibrium. We do this by stating more elaborate characterizations underlying the above proposition, accompanied by proofs. The proofs are partial in the sense that each characterizations takes as given the other characterizations, and the general proof involves the whole set of characterizations and proofs together. The first case is that of perpetual growth in section 5.2.2, the second in section 5.2.3 concerns the cycle, and we lastly deal with the transient states in section 5.2.4. Section 5.2.5 points to some general properties of equilibria, and in section 5.2.6 we lastly show that there are parameter values such that there is another political equilibrium: one with perpetual stagnation.

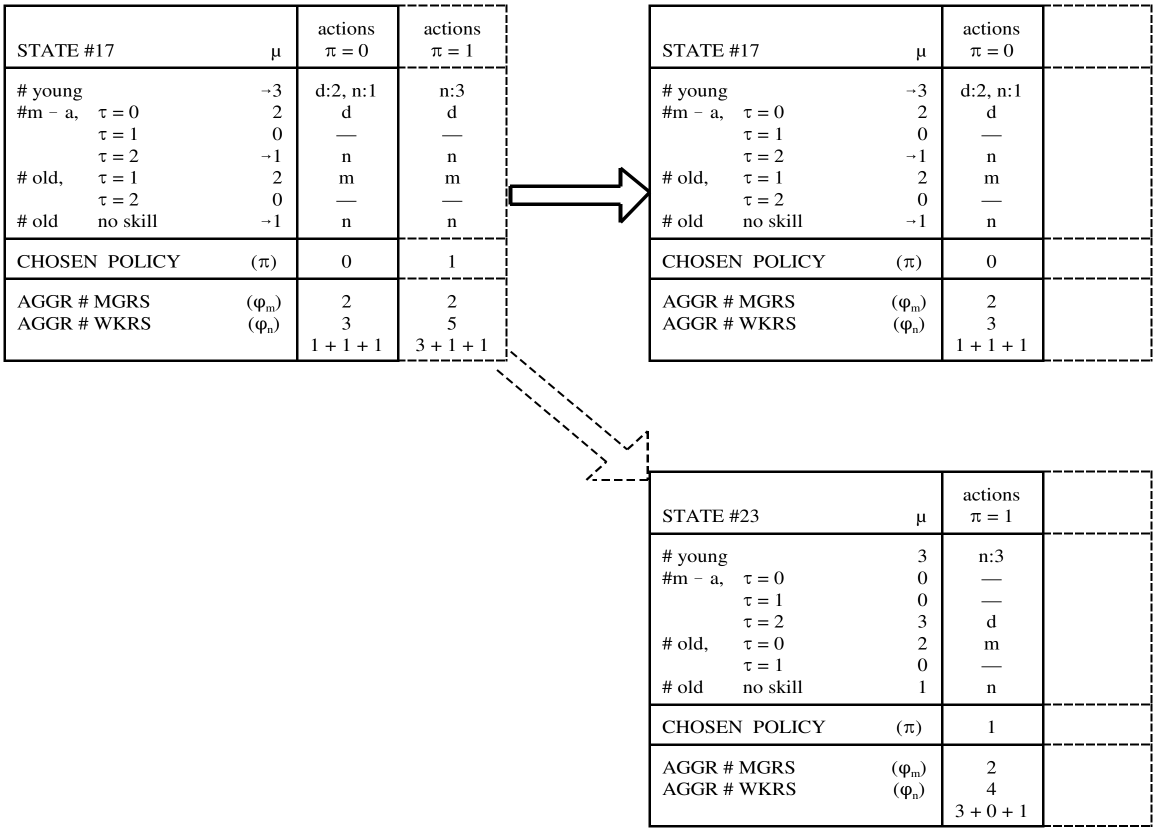
5.2.2 Perpetual growth

We now discuss and verify our steady state with perpetual growth of section 3.2.

Characterization 1 *The equilibrium has an ergodic set with a unique element. We label this state a steady state, i.e. a state $\mu^\star$ s.t. $\mu^\star = h(\mu^\star)$. This steady state has innovation, and its gross long-run growth rate of consumption is equal to γ. There are two innovators and one worker per cohort; all innovators and managers are against growth, and all young agents and workers are in favor of growth. The vote in favor of growth is 5-4.*

PROOF: The state labeled 17 in Figure 1 corresponds to the steady state with growth as studied in the section with exogenous policy. Figure 2 describes this steady state in more detail. In it, state 17 is described as well as the actions taken under the winning policy in a box with continuous lines, and under the losing policy in a box with discontinuous lines. In the figure, the members of the winning coalition are marked with small arrows. The large solid arrow points to the state next period under the winning policy, while the large dashed arrow points to the state to which the economy would have gone under the losing policy. The equilibrium vote is as conjectured in section 5.1.

To see this, note first that in the case of $\pi = 0$, two agents innovate, and there is a total of 3 (1 young + 1 middle-aged + 1 old) workers the current period and the same in the next (all consecutive) periods. With the alternative policy, $\pi = 1$, the current number of young workers would be 3 and the total $3+1+1 = 5$. The next period the state would then be state 25, which differs from state 17 only in the distribution of its middle-aged, since these middle-aged were not able to innovate when young (and all other agents would make the same choices as for $\pi = 0$). In state 23 the the majority vote is not to allow growth, and hence all young agents work. The middle-aged choose to retrain in this state over switching and giving up being able to manage in the consecutive period. Hence, the the total number of workers in state 23 is then $3 + 0 + 1 = 4$. Going back to the voting decision in state 17, the old managers prefer to regulate, since it implies a higher number of current workers, and hence higher demand (i.e. total consumption) and higher R/P (see our price characterization in section 5.1). Old workers have the opposite opinion—they prefer low current demand (i.e. low total consumption) and a low $1/P$, and hence favor innovation. The middle-aged on a working career face a lower present product price for $\pi = 0$ than for $\pi = 1$, but these agents also care about the product price in the following period. This price does depend on the current value of π, since it affects both tomorrow's skill distribution, tomorrow's vote and hence price. As seen in the figure, there will be lower product prices and higher profits in the following period, since the total number of workers in that period is lower if the state is 17 (3) than if the state is 23 (4). Therefore, the middle-aged workers prefer innovation in the current period, giving them higher purchasing power in both periods. Similarly, the middle-aged agents on a managerial career are against growth since $\pi = 1$ implies higher future profits (which is all they care about). All in all, there are 5 agents in favor of innovation, and 4 against. Similarly, we need to verify the properties of state 11 and 23. Complete arguments for this are provided by Figures 3 and 4 in the back of the paper. □



STATE #17	μ	actions $\pi = 0$	actions $\pi = 1$
# young	→3	d:2, n:1	n:3
#m − a, $\tau = 0$	2	d	d
$\tau = 1$	0	—	—
$\tau = 2$	→1	n	n
# old, $\tau = 1$	2	m	m
$\tau = 2$	0	—	—
# old no skill	→1	n	n
CHOSEN POLICY (π)		0	1
AGGR # MGRS (φ_m)		2	2
AGGR # WKRS (φ_n)		3	5
		1 + 1 + 1	3 + 1 + 1

STATE #17	μ	actions $\pi = 0$	
# young	→3	d:2, n:1	
#m − a, $\tau = 0$	2	d	
$\tau = 1$	0	—	
$\tau = 2$	→1	n	
# old, $\tau = 1$	2	m	
$\tau = 2$	0	—	
# old no skill	→1	n	
CHOSEN POLICY (π)		0	
AGGR # MGRS (φ_m)		2	
AGGR # WKRS (φ_n)		3	
		1 + 1 + 1	

STATE #23	μ	actions $\pi = 1$	
# young	3	n:3	
#m − a, $\tau = 0$	0	—	
$\tau = 1$	0	—	
$\tau = 2$	3	d	
# old, $\tau = 0$	2	m	
$\tau = 1$	0	—	
# old no skill	1	n	
CHOSEN POLICY (π)		1	
AGGR # MGRS (φ_m)		2	
AGGR # WKRS (φ_n)		4	
		3 + 0 + 1	

Figure 2

This characterization is in line with the conjectures in section 5.1, but it involves more detail: it also checks the effect of the current policy on the prices in the following period, which the middle-aged agents care about. The majority coalition consists of 3 young, 1 middle-aged, and 1 old agents. The key behind supporting the vote in favor of innovation in state 17 is the size of groups—the number of workers per generation is high enough here to make up a total majority together with the young agents.

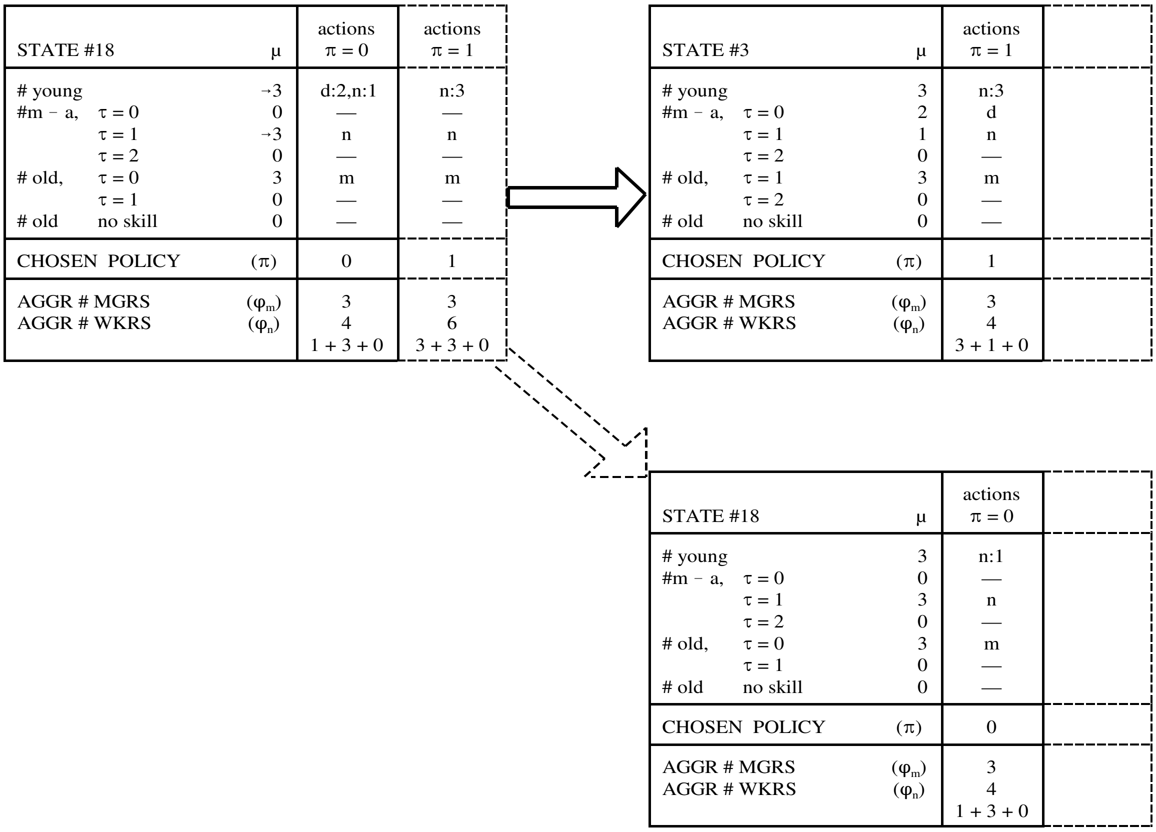
5.2.3 The cycle

Our discussion of the cycle will involve studying in detail how the economy goes from state 18 to state 3 (Figure 5), from state 3 to state 21 (Figure 6), and from state 21 back to state 18 (Figure 7). A description of the main features of this process is

Characterization 2 *There is a three-period cycle, i.e. a state* $\mu^{\star\star}$ *such that* $h(h(h(\mu^{\star\star}))) = \mu^{\star\star}$*, with the property that* $\Psi(\mu^{\star\star}) = 0$ *and* $\Psi(h(\mu^{\star\star})) = \Psi(h(h(\mu^{\star\star}))) = 1$*. Only in state* $\mu^{\star\star}$ *will there be innovation; in that state, 2 among the cohort of young agents become innovators. These innovators then form part of the coalition that decides the vote in the two following periods. More precisely, the coalitions deciding the vote are: in state* $\mu^{\star\star}$*, the young and the middle-aged* ($\pi = 0$)*; in state* $h(\mu^{\star\star})$*, the middle-aged innovators and the old managers* ($\pi = 1$)*; and in state* $h(h(\mu^{\star\star}))$*, the middle-aged and the old innovators from two periods ago. The average long-run growth rate in the stagnation-growth cycle is* $\gamma^{\frac{1}{3}}$*.*

PROOF: We label the three states $\mu^{\star\star}$, $h(\mu^{\star\star})$, and $h(h(\mu^{\star\star}))$ with 18, 3, and 21, respectively. Figures 5 to 7 describe the mechanics of the cycle in detail. First, Figure 5 shows that state 18 is the most backward state—it is the "medieval" state—since all its old agents have the same ability to manage the state-of-the-art technology (they can be "masters"), and the middle-aged have one period of experience in that same technology. The key political element in state 18 is that the middle-aged turn out in favor of breaking out of stagnation. They see, on the one hand, that their current purchasing power increases with innovation, but that on the other, it also takes away demand for the product they will sell the next period as managers. It turns out, however, that in this case the total sales next period, and hence their profits, are the same (with $\varphi_n = 4$) whether there is innovation today or not. This is because saying no to growth today actually also changes the vote the next period: it simply postpones adoption of the new technology one period; if growth is allowed there will be 4 (1 middle-aged and 3 young) workers tomorrow (state 3); if it is postponed one period, there will also be 4 (3 middle-aged and 1 young) workers (state 18). Hence the preference of the middle-aged in state 18 is to allow adoption of new technologies, since this at least raises the current real wage. The winning coalition in state 18 is therefore the young and the middle-aged, who both agree to allow innovation.

Second, Figure 6 shows that the next state, 3, has two groups of middle-aged as a result of the innovation in state 18: there are 2 innovators and 1 worker. This time the winning coalition consists of no-sayers. These comprise the current old and the 2 developers, whose vested interests speak against development: they only care about the number of workers they can attract as buyers the following period, and a no to growth maximizes the work force. First, saying no to growth tips tomorrow's policy outcome against growth, and hence implies that there will be 3 young workers in that state (state 21) as opposed to 1 if the current vote were to allow innovation and the economy were to go to state 11. Counteracting this is the fact that in state 21, all the middle-aged decide to retrain, and hence provide no demand—they will consume the period after that, as managers. In the alternative state, state 11, there would be some demand from the middle-aged, namely from the middle-aged agent who did not innovate. However, the net of these two effects is that the middle-aged innovators in state 3 prefer to vote for $\pi = 1$—the total consumption of the good they produce is higher in state 21 than in state 11 ($4 > 3$). They therefore side with the 3 old managers and make up a majority voting out growth 5-4.



STATE #18		μ	actions $\pi = 0$	actions $\pi = 1$
# young		→3	d:2,n:1	n:3
#m − a,	$\tau = 0$	0	—	—
	$\tau = 1$	→3	n	n
	$\tau = 2$	0	—	—
# old,	$\tau = 0$	3	m	m
	$\tau = 1$	0	—	—
# old	no skill	0	—	—
CHOSEN POLICY		(π)	0	1
AGGR # MGRS		(φ_m)	3	3
AGGR # WKRS		(φ_n)	4 1 + 3 + 0	6 3 + 3 + 0

STATE #3		μ	actions $\pi = 1$
# young		3	n:3
#m − a,	$\tau = 0$	2	d
	$\tau = 1$	1	n
	$\tau = 2$	0	—
# old,	$\tau = 1$	3	m
	$\tau = 2$	0	—
# old	no skill	0	—
CHOSEN POLICY		(π)	1
AGGR # MGRS		(φ_m)	3
AGGR # WKRS		(φ_n)	4 3 + 1 + 0

STATE #18		μ	actions $\pi = 0$
# young		3	n:1
#m − a,	$\tau = 0$	0	—
	$\tau = 1$	3	n
	$\tau = 2$	0	—
# old,	$\tau = 0$	3	m
	$\tau = 1$	0	—
# old	no skill	0	—
CHOSEN POLICY		(π)	0
AGGR # MGRS		(φ_m)	3
AGGR # WKRS		(φ_n)	4 1 + 3 + 0

Figure 5

In state 21 (see Figure 7), there is again a coalition making up a majority against growth. This coalition consists of 2 old innovator-managers and 3 middle-aged workers. The latter agents choose to sit out and retrain in the currently producing technology so as to be able to become managers for this technology in the following period (state 18)—this activity dominates switching, which would have left the economy entirely without managers in the following period. These middle-aged agents form part of the winning political coalition even though they are actually indifferent with respect to the current policy: the current wage rate is irrelevant to them, and both policies imply the same number of workers the following period: state 18 as well as state 3 have four workers (although with different age compositions).[19]

Finally, to support the asserted claims about the behavior in state 11, which, in turn, involves understanding that state 11 leads to state 17, we refer to Figures 2 to 4 for complete arguments. □

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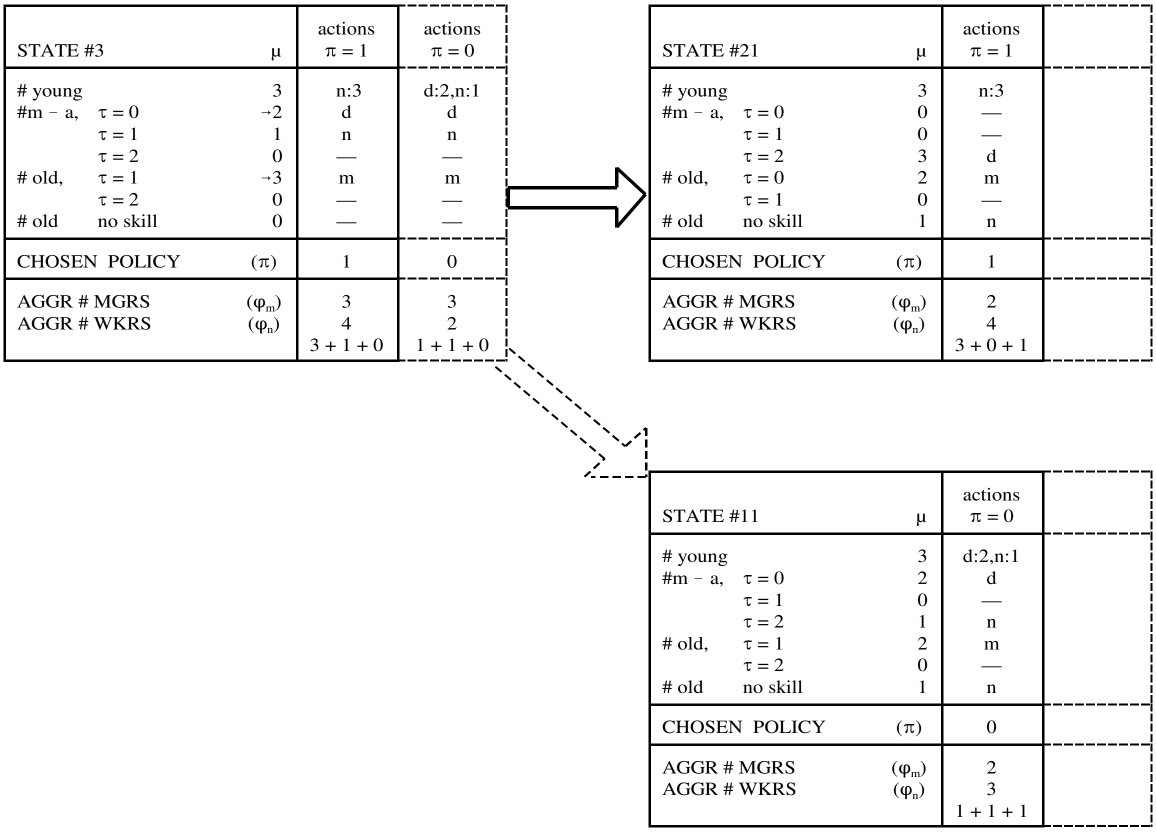
[19] Although it is true that the winning majority may seem weak since a part of it is indifferent, there are minor alterations of the model which would break the indifference and produce the same outcome. One such alteration is that middle-aged workers, while still being perfect substitutes with young workers, have slightly higher productivity than the young workers.



STATE #3		μ	actions $\pi = 1$	actions $\pi = 0$
# young		3	n:3	d:2,n:1
#m − a,	$\tau = 0$	→2	d	d
	$\tau = 1$	1	n	n
	$\tau = 2$	0	—	—
# old,	$\tau = 1$	→3	m	m
	$\tau = 2$	0	—	—
# old	no skill	0	—	—
CHOSEN POLICY		(π)	1	0
AGGR # MGRS AGGR # WKRS		(φ_m) (φ_n)	3 4 3 + 1 + 0	3 2 1 + 1 + 0

STATE #21		μ	actions $\pi = 1$	
# young		3	n:3	
#m − a,	$\tau = 0$	0	—	
	$\tau = 1$	0	—	
	$\tau = 2$	3	d	
# old,	$\tau = 0$	2	m	
	$\tau = 1$	0	—	
# old	no skill	1	n	
CHOSEN POLICY		(π)	1	
AGGR # MGRS AGGR # WKRS		(φ_m) (φ_n)	2 4 3 + 0 + 1	

STATE #11		μ	actions $\pi = 0$	
# young		3	d:2,n:1	
#m − a,	$\tau = 0$	2	d	
	$\tau = 1$	0	—	
	$\tau = 2$	1	n	
# old,	$\tau = 1$	2	m	
	$\tau = 2$	0	—	
# old	no skill	1	n	
CHOSEN POLICY		(π)	0	
AGGR # MGRS AGGR # WKRS		(φ_m) (φ_n)	2 3 1 + 1 + 1	

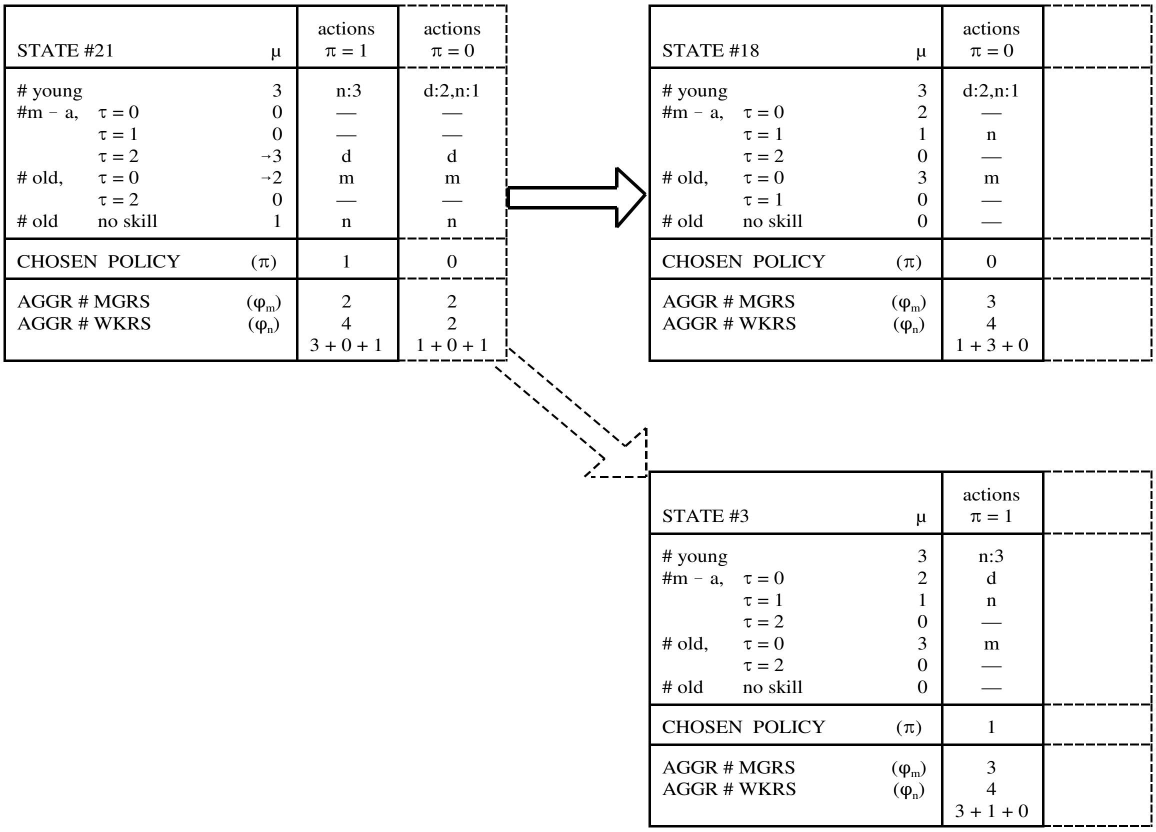
Figure 6

Note that in order to verify that the cycle is an equilibrium (and also in order to verify that state 28 is a steady state) it was necessary to discuss all the states 18, 3, 21, 11, 23, and 17.

5.2.4 The transient states

For completeness, a description of all the equilibrium elements (for the 23 states) can be found in Table 1 in the back of the paper. The table describes all the relevant aspects of the cycle and the perpetual growth equilibrium. It thus lists the 23 values of the state variable in columns 2-8; the index s in column 1 enumerates the states. Columns 2-4 describe the number of middle-aged agents of different types ($\mu_{20}, \mu_{21}, \mu_{22}$), and the next four columns list the number of old agents of different types ($\mu_{30}, \mu_{31}, \mu_{32}, \mu_3$). As regards the properties of the different states, note that state 18 is the medieval state, and that states 13 and 17 are the potential steady states with growth in every period.

The parentheses next to the number of agents in columns 2-8 indicate the equilibrium voting behavior for the respective types. Moreover, the table describes the laws of motion of the state variable, μ. The economic actions are not described explicitly. However, if the



STATE #21		μ	actions π = 1	actions π = 0
# young		3	n:3	d:2,n:1
#m − a,	τ = 0	0	—	—
	τ = 1	0	—	—
	τ = 2	→3	d	d
# old,	τ = 0	→2	m	m
	τ = 2	0	—	—
# old	no skill	1	n	n
CHOSEN POLICY		(π)	1	0
AGGR # MGRS		(φ_m)	2	2
AGGR # WKRS		(φ_n)	4	2
			3 + 0 + 1	1 + 0 + 1

STATE #18		μ	actions π = 0
# young		3	d:2,n:1
#m − a,	τ = 0	2	—
	τ = 1	1	n
	τ = 2	0	—
# old,	τ = 0	3	m
	τ = 1	0	—
# old	no skill	0	—
CHOSEN POLICY		(π)	0
AGGR # MGRS		(φ_m)	3
AGGR # WKRS		(φ_n)	4
			1 + 3 + 0

STATE #3		μ	actions π = 1
# young		3	n:3
#m − a,	τ = 0	2	d
	τ = 1	1	n
	τ = 2	0	—
# old,	τ = 0	3	m
	τ = 2	0	—
# old	no skill	0	—
CHOSEN POLICY		(π)	1
AGGR # MGRS		(φ_m)	3
AGGR # WKRS		(φ_n)	4
			3 + 1 + 0

Figure 7

current state is μ and next period's state is μ', then it is clear what today's choices of the currently middle-aged and young must be.[20]

The right-hand side of the table describes the functions h_μ, H_μ, and the political outcome function Ψ. This information enables us to completely describe the dynamics of the skill distribution and the policy outcome for any initial skill distribution in the set of 23. It also shows how alternative policies would affect the system over time: this is described by $H_\mu(\mu, \Psi^{\mathbf{c}}(\mu))$ (here $^{\mathbf{c}}$ denotes the alternative policy). This information is crucial to the agents when they form their preferences over the different policies. Finally, next to $\Psi(\mu)$ we also list the total vote count.

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[20] The actions of the currently old agents cannot be read off tomorrow's state, but it is true throughout that old behave according to our conjecture: if they have skills in the newest technology, they manage this technology; if they have no skills, they work in the newest technology; and if they have skills in technology 2, prices are such that they choose not to operate their technology, but instead work as unskilled in technology 1.

5.2.5 Some general properties

It is clear from inspection of Table 1 that 13 out of the 23 states lead to the cycle, and the remaining 10 to perpetual growth. Along the paths toward regulation, it is possible that innovation is initially allowed, but eventually there is a large enough vested interest in the old technologies that the economy ends up in the cycle of stagnation and growth. The longest transition to the stagnation-growth cycle in our example spans three periods, for example from state 6, via 5 and 23, to state 18.

The transition to prosperity is at most 2 periods long. Along all these paths growth is allowed. Hence, a no-to-growth once is a sufficient, but not necessary, signal that the economy will end up in the cycle.

It is crucial that the agents take into account how a change in the current policy affects the future path of skill distributions and policy outcomes. Indeed, in all states we find that a change in the current value of π also implies a change in the policy next period, and these effects are key to the equilibrium characteristics.

What properties of the skill distribution are indicative of where the economy is heading? We note that the composition of the middle-aged is important in this respect. If either all or none among the middle-aged are innovators, then the economy will end up in the stagnation cycle. When the number of middle-aged innovators, who all are against growth, together with the number of old managers is large enough to form a majority (≥ 5), then growth will be voted down, and the stagnation cycle result. When there is only one manager but three middle-aged innovators (states 6 and 12), this coalition does not have a majority, and growth is allowed. Even here, however, the stagnation cycle will result: allowing growth for our parameter values always means that two young agents will innovate and one young agent work, and the two young innovators will form a majority coalition against innovation in the next period with the three currently middle-aged innovators.

Also in the case where there are no middle-aged innovators, the political equilibrium leads to low average growth (i.e. to the cycle). In states 19-23, the middle-aged agents retrain and in fact are indifferent with respect to the policy outcome: whether or not there will be regulation, next period's profits will be the same.[21] In some of these states there will be innovation, and in others there will not.

When there are 1 or 2 innovators among the currently middle-aged, growth may or may not result; the middle-aged workers are now sure that they will not be managers next period

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[21] Had these agents abstained, there would have been a reverse outcome in states 19, 21, and 23. However, footnote 19 in the previous subsection applies: there is a minor alteration of the the model which would give the same result without this indifference.

(since there are better managers around), and as workers they prefer growth, because growth keeps the labor force smaller and they get higher wages that way. In these cases, the political decisions of the currently old agents are pivotal, and depending on the exact distribution, the economy goes to the cycle or to state 17.

5.2.6 Perpetual stagnation

For the second economy there is also a different equilibrium: an equilibrium without cycles, but instead with perpetual stagnation, as described in the section above on steady states for given policies.

Proposition 3 *For the second economy there exists an equilibrium satisfying the same conditions as (1)-(3) of Proposition 1, with*
(4′) There are 2 ergodic sets with a unique element each: one with perpetual growth ($\pi = 0$), and one with perpetual stagnation ($\pi = 1$).
(5′) The other 21 states are transient: 12 lead to perpetual growth, and the remaining 9 lead to perpetual stagnation.

This second type of equilibrium is described in Table 2. In the medieval state 18, the one that is associated with a long spell of previous stagnation, the policy is not to allow growth; in particular, the middle-aged do not find it optimal to support growth. In this equilibrium, the middle-aged are faced with the nontrivial choice indicated in section 5.1: these agents realize that whereas the number of young workers the next period is unaffected by the current policy—tomorrow's state, whether 18 or 3, is one where innovation is not allowed—the current policy matters for the number of middle-aged workers they will have the next period. Hence if innovation is prohibited in the current period, there will be a larger number of workers next period, but there will also be a larger number of competing workers in the current period, than if innovation is allowed. The political preference of these agents therefore involves an intertemporal consideration, and this equilibrium will only exists for some parameter values. In terms of our two sets of parameter values, the discount factor is relatively lower in the second economy, and in this case the payoff from allowing the young to innovate—the higher current purchasing power—is greater than the discounted cost—the lower future profits—so the middle-aged will vote yes to growth in this case. This explains why for lower discount factors this type of equilibrium does not exist.

6 Concluding Remarks

We constructed a model where vested interests were responsible for the prohibition of technological innovation. In the economy studied, there is a permanent tension in the political process between agents with different types of skill. Growth is always a possibility, and whether it occurs or not depends on properties of the current distribution of agents over capital specialization. The particular features of this distribution that matter to the outcome can be explained from economic and political fundamentals. We have a few final remarks.

First, to summarize the fundamentals that matter to the long run growth outcome proved surprisingly hard for some initial distributions even in this simple economy—it is clear what policy *outcomes* lead to growth, but to understand their *determination* is a much less trivial task. We saw that the middle-aged agents were important to the final outcome, and that the distribution of old agents mattered as well. Moreover, neither were the particular distributions of skills within these groups that lead to growth trivial to characterize. Hence, it was necessary to study subtle aspects of the interplay between economics and politics to fully understand the long-run growth outcome. Our results indicate that it may be difficult in many cases to identify reasons for growth based on analyzing crude macroeconomic aggregates—it is not obvious that the key characteristics of the distribution of skills are either observable or easily summarizable with simple statistics. Our findings also point to the intrinsic insufficiency of studying steady states: since dynamics have to be analyzed to support any steady state, analyzing dynamics is unavoidable. This also means that comparative statics exercises are much harder here than in dynamic models where the policy is exogenous.

Second, cycles in the adoption of techniques can also occur as a result of special properties of the production technologies, as in the Parente (1990) model of technology adoption. Breziz, Krugman, & Tsiddon (1991) study a similar setting with two countries, and they find that different countries adopt new techniques, and become technological "leaders", at different times in such a way that world-wide production is efficient. The cycles of stagnation and growth that result in our framework do not rely on special aspects of the production technology other than heterogeneity of techniques. The kind of cycles we obtain could naturally also occur in multi-country settings, although we have yet to explore all the implications of trade between countries.

Third, our positive analysis is far away from understanding what countries or regions might want to *do* to avoid stagnation outcomes. A general problem is that the set of policies considered, as in most political equilibrium theory, is severely restricted. Alternative policy packages in our framework, e.g. those including yes to growth but compensation to the agents losing from the introduction of new techniques, might well attract a majority of voters. We rule out these packages with a vague reference to real world economies.[22] But why aren't these kinds of packages used more often in real economies? This is the key question that needs to be addressed in future research in order to understand the role of different political institutions.

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[22] Note that in fact not all compensation schemes would work in our model as some transfers from the young to the old will imply negative consumption.

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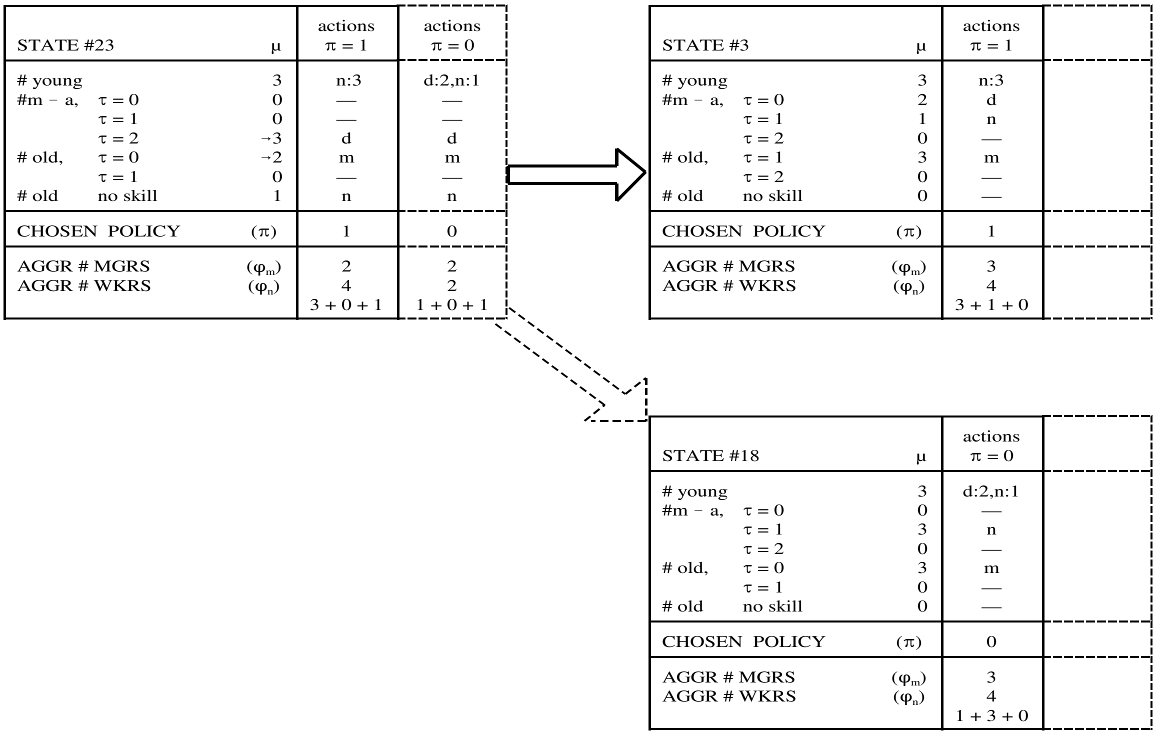
Skill distributions (Individual votes)								Aggregate laws of motion		Policy outcomes
s	μ_{20} (ψ_{20})	μ_{21} (ψ_{21})	μ_{22} (ψ_{22})	μ_{30} (ψ_{30})	μ_{31} (ψ_{31})	μ_{32} (ψ_{32})	μ_{3} (ψ_{3})	$h_\mu(\mu)$	$H_\mu(\mu, \Psi^{\mathbf{c}}(\mu))$	$\Psi(\mu)$ (count)
A. The middle-aged have more advanced skills:										
1	3 (1)				3 (1)			19	5	1 (6-3)
2	1 (1)	2 (0)			3 (1)			8	20	0 (5-4)
$3^{\star}$	2 (1)	1 (0)			3 (1)			21	11	1 (5-4)
4	1 (1)		2 (0)		3 (1)			14	22	0 (5-4)
5	2 (1)		1 (0)		3 (1)			23	17	1 (5-4)
6	3 (1)				1 (1)	2 (0)		5	19	0 (5-4)
7	1 (1)		2 (0)		1 (1)	2 (0)		14	22	0 (7-2)
8	2 (1)		1 (0)		1 (1)	2 (0)		17	23	0 (6-3)
9	3 (1)				2 (1)	1 (0)		19	5	1 (5-4)
10	1 (1)		2 (0)		2 (1)	1 (0)		14	22	0 (6-3)
11	2 (1)		1 (0)		2 (1)	1 (0)		17	23	0 (5-4)
12	3 (1)				1 (1)		2 (0)	5	19	0 (5-4)
13	1 (1)		2 (0)		1 (1)		2 (0)	14	22	0 (7-2)
14	2 (1)		1 (0)		1 (1)		2 (0)	17	23	0 (6-3)
15	3 (1)				2 (1)		1 (0)	19	5	1 (5-4)
16	1 (1)		2 (0)		2 (1)		1 (0)	14	22	0 (6-3)
$17^{\star}$	2 (1)		1 (0)		2 (1)		1 (0)	17	23	0 (5-4)
B. The old and middle-aged have the same skills:										
$18^{\star}$	3 (0)			3 (1)				3	18	0 (6-3)
C. The old have more advanced skills:										
19		3 (1)		3 (1)				18	3	1 (6-3)
20		3 (1)		1 (1)	2 (0)			3	18	0 (5-4)
$21^{\star}$		3 (1)		2 (1)	1 (0)			18	3	1 (5-4)
22		3 (1)		1 (1)			2 (0)	3	18	0 (5-4)
23		3 (1)		2 (1)			1 (0)	18	3	1 (5-4)

Table 1: Equilibrium distributions, laws of motion, and voting results in economies 1 and 2. Notes: (1) The young always vote 0 (yes to growth). (2) A * refers to an ergodic state.

Skill distributions (Individual votes)								Aggregate laws of motion		Policy outcomes
s	μ_{20} (ψ_{20})	μ_{21} (ψ_{21})	μ_{22} (ψ_{22})	μ_{30} (ψ_{30})	μ_{31} (ψ_{31})	μ_{32} (ψ_{32})	μ_{3} (ψ_{3})	$h_\mu(\mu)$	$H_\mu(\mu, \Psi^{\mathbf{c}}(\mu))$	$\Psi(\mu)$ (count)
A. The middle-aged have more advanced skills:										
1	3 (1)				3 (1)			19	5	1 (6-3)
2	1 (1)	2 (0)			3 (1)			8	20	0 (5-4)
3	2 (1)	1 (0)			3 (1)			21	11	1 (5-4)
4	1 (1)		2 (0)		3 (1)			14	22	0 (5-4)
5	2 (1)		1 (0)		3 (1)			23	17	1 (5-4)
6	3 (1)				1 (1)	2 (0)		5	19	0 (5-4)
7	1 (1)		2 (0)		1 (1)	2 (0)		14	22	0 (7-2)
8	2 (1)		1 (0)		1 (1)	2 (0)		17	23	0 (6-3)
9	3 (1)				2 (1)	1 (0)		19	5	1 (5-4)
10	1 (1)		2 (0)		2 (1)	1 (0)		14	22	0 (6-3)
11	2 (1)		1 (0)		2 (1)	1 (0)		17	23	0 (5-4)
12	3 (1)				1 (1)		2 (0)	5	19	0 (5-4)
13	1 (1)		2 (0)		1 (1)		2 (0)	14	22	0 (7-2)
14	2 (1)		1 (0)		1 (1)		2 (0)	17	23	0 (6-3)
15	3 (1)				2 (1)		1 (0)	19	5	1 (5-4)
16	1 (1)		2 (0)		2 (1)		1 (0)	14	22	0 (6-3)
$17^\star$	2 (1)		1 (0)		2 (1)		1 (0)	17	23	0 (5-4)
B. The old and middle-aged have the same skills:										
$18^\star$	3 (1)			3 (1)				18	3	0 (6-3)
C. The old have more advanced skills:										
19		3 (1)		3 (1)				18	3	1 (6-3)
20		3 (1)		1 (1)	2 (0)			3	18	0 (5-4)
21		3 (1)		2 (1)	1 (0)			18	3	1 (5-4)
22		3 (1)		1 (1)			2 (0)	3	18	0 (5-4)
23		3 (1)		2 (1)			1 (0)	18	3	1 (5-4)

Table 2: Equilibrium distributions, laws of motion, and voting results in economy 1. Notes: (1) The young always vote 0 (yes to growth). (2) A * refers to an ergodic state.

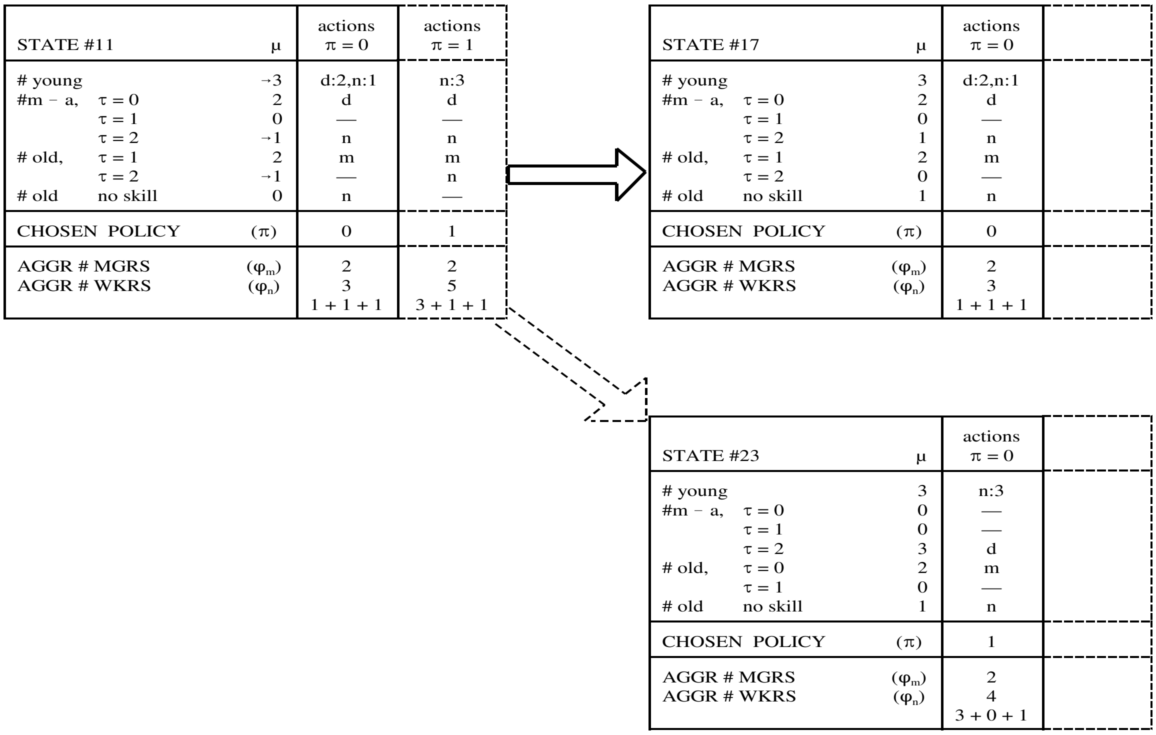


STATE #23		μ	actions $\pi = 1$	actions $\pi = 0$
# young		3	n:3	d:2,n:1
#m − a,	$\tau = 0$	0	—	—
	$\tau = 1$	0	—	—
	$\tau = 2$	→3	d	d
# old,	$\tau = 0$	→2	m	m
	$\tau = 1$	0	—	—
# old	no skill	1	n	n
CHOSEN POLICY		(π)	1	0
AGGR # MGRS		(φ_m)	2	2
AGGR # WKRS		(φ_n)	4	2
			3 + 0 + 1	1 + 0 + 1

STATE #3		μ	actions $\pi = 1$
# young		3	n:3
#m − a,	$\tau = 0$	2	d
	$\tau = 1$	1	n
	$\tau = 2$	0	—
# old,	$\tau = 1$	3	m
	$\tau = 2$	0	—
# old	no skill	0	—
CHOSEN POLICY		(π)	1
AGGR # MGRS		(φ_m)	3
AGGR # WKRS		(φ_n)	4
			3 + 1 + 0

STATE #18		μ	actions $\pi = 0$
# young		3	d:2,n:1
#m − a,	$\tau = 0$	0	—
	$\tau = 1$	3	n
	$\tau = 2$	0	—
# old,	$\tau = 0$	3	m
	$\tau = 1$	0	—
# old	no skill	0	—
CHOSEN POLICY		(π)	0
AGGR # MGRS		(φ_m)	3
AGGR # WKRS		(φ_n)	4
			1 + 3 + 0

Figure 3



STATE #11		μ	actions $\pi = 0$	actions $\pi = 1$
# young		→3	d:2,n:1	n:3
#m − a,	$\tau = 0$	2	d	d
	$\tau = 1$	0	—	—
	$\tau = 2$	→1	n	n
# old,	$\tau = 1$	2	m	m
	$\tau = 2$	→1	—	n
# old	no skill	0	n	—
CHOSEN POLICY		(π)	0	1
AGGR # MGRS		(φ_m)	2	2
AGGR # WKRS		(φ_n)	3	5
			1 + 1 + 1	3 + 1 + 1

STATE #17		μ	actions $\pi = 0$
# young		3	d:2,n:1
#m − a,	$\tau = 0$	2	d
	$\tau = 1$	0	—
	$\tau = 2$	1	n
# old,	$\tau = 1$	2	m
	$\tau = 2$	0	—
# old	no skill	1	n
CHOSEN POLICY		(π)	0
AGGR # MGRS		(φ_m)	2
AGGR # WKRS		(φ_n)	3
			1 + 1 + 1

STATE #23		μ	actions $\pi = 0$
# young		3	n:3
#m − a,	$\tau = 0$	0	—
	$\tau = 1$	0	—
	$\tau = 2$	3	d
# old,	$\tau = 0$	2	m
	$\tau = 1$	0	—
# old	no skill	1	n
CHOSEN POLICY		(π)	1
AGGR # MGRS		(φ_m)	2
AGGR # WKRS		(φ_n)	4
			3 + 0 + 1

Figure 4