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Industry Evolution and Transition: Measuring Investment in Organization Capital

Andrew Atkeson*

University of Pennsylvania
and National Bureau of Economic Research

Patrick J. Kehoe*

Federal Reserve Bank of Minneapolis,
University of Pennsylvania,
and University of Minnesota

ABSTRACT

We use a calibrated model of the dynamics of organization capital and industry evolution to measure the size of investment in organization capital in the steady state and the dynamics of organization capital during the transition following a major reform. We find that, in the steady state, aggregate net investment in organization capital is roughly one-fifth of measured output. During the initial phase of transition, the failure rate of plants rises 200–400 percent, measured output and aggregate productivity stagnate, physical investment falls, and net investment in organization capital rises between 300 and 500 percent above its steady-state level.

*The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.

1 Introduction

In recent years, many countries have undertaken major reforms of their economic policies. Often they subsequently experienced a transition in which many old, productive organizations shrank or were disbanded and new, productive ones appeared to replace them. We view the evolution of industry during the transition following reform as an investment in new organization capital. During the transition, agents discard outmoded organization capital in old enterprises and invest in new organization capital in new enterprises to take advantage of opportunities presented by the policy reforms. At the macro level, in a number of these countries it has taken several years for the benefits of such reforms to show up in increased output and productivity. (See the report of the World Bank 1992, which documents this phenomenon.) We believe that, following reform, the process of investment in organization capital plays an important role in shaping the dynamics of transition at the aggregate level. Our objective in this paper is to measure the aggregate scale of this investment in organization capital and study its impact on the path of measured output, productivity, and physical investment.

Investment in organization capital is not measured in the standard National Income and Product Accounts (NIPA). We propose a measure of the value of net investment in organization capital, which in our model is similar to the one used in the NIPA accounts for net investment in physical capital. Standard accounting methods measure investment by using data on the prices and quantities of capital goods. Direct measures of prices and quantities of organization capital are not available. Thus, in order to measure investment in organization capital, we need a model by which to infer its prices and quantities. We develop such a model and use it to measure aggregate investment in organization capital, both in the steady state and during the transition following a stylized reform. We also present our model's implications for the path of aggregate output, total factor productivity, investment in physical capital, and patterns of industry evolution during the transition.

At the micro level, our paper is based on the idea that organizations serve to store and accumulate information that affects their technology of production. At least as far back as Marshall (1920), this idea has been central to the theory of the firm. Marshall discussed

how industry evolution is determined by the dynamics of the process by which organizations acquire such information. We follow Prescott and Visscher (1980) in calling this information *organization capital*. Two broad themes have emerged from the literature following Marshall. One is that organization capital is embodied in the workers in the firm, or in their matches to tasks within the firm. Jovanovic (1979), Prescott and Visscher (1980), Becker (1993), and others have developed explicit micro models of this idea. Telser (1972), Jovanovic and Moffitt (1990), Topel (1991), and others have measured different aspects of this firm-specific human capital. A second theme is that organization capital is a firm-specific capital good jointly produced with output and embodied in the organization itself. Arrow (1962), Rosen (1972), and many others have developed models in which organization capital is acquired through learning-by-doing. Bahk and Gort (1993) measured the accumulation of organization capital in new plants within U.S. manufacturing industries. We follow this second theme; we regard organization capital as embodied in the organization itself and as being jointly produced with measured output. We follow Lucas (1993), Parente and Prescott (1994), and others in emphasizing the importance of unmeasured investment in organization capital for shaping the transition and growth of the economy as a whole.

Our model of organization capital and industry evolution builds on these basic models of the firm; thus it is related to the industry evolution models of Jovanovic (1982), Nelson and Winter (1982), and Hopenhayn and Rogerson (1993). The productivity of the individual plant is determined by its stock of organization capital and the vintage of its technology. As a plant operates over time, its stock of organization capital grows stochastically. We interpret the growth of a plant's organization capital as arising from a stochastic learning process. If a plant learns, its productivity rises. If a plant fails to learn, its productivity falls and, eventually, the plant dies. When new plants are born (enter), they embody the best available (or frontier) technology, but they have little organization capital. They begin with relatively low productivity and tend to improve their organization capital rapidly. Older plants, with older technologies, have larger stocks of organization capital but learn at a less rapid rate. Plants die (exit) when the discounted returns to the owner of the organization capital in the plant fall to zero. In this manner, our model describes the dynamics of birth, growth, and death for individual plants.

We calibrate the steady state of our model to match panel data on the birth, growth, and death of manufacturing plants in the U.S. and standard macro aggregates from the U.S. economy. To do so, we use panel data on the distribution of the growth rate of employment in plants of different ages. Each year, large numbers of existing plants die and many other new plants are born. For example, Davis and Haltiwanger (1991) document that roughly 7 percent of the manufacturing plants in the United States die each year and a similar number of new plants are born. Roughly half of all plants expand or contract employment by 15 percent or more each year. The data on the evolution of new plants is particularly striking. New plants employ, on the average, only one-tenth of the labor employed in the typical plant. It is not until plants are ten years old that they grow to be as large, on the average, as the typical plant. Furthermore, Dunne, Roberts, and Samuelson (1989) document that 40 percent of new plants fail within the first five years. Within the context of our model, these data suggest that the learning process is both turbulent and time-consuming. When we calibrate our model to replicate this turbulent process, we find that, in the steady state of our model, aggregate net investment in organization capital is roughly one-fifth of measured output.

We next study the dynamics of investment in organization capital during the transition following a major reform. We model reform as a sudden improvement in the quality of the technologies available to new plants in the reformed economy. To illustrate these dynamics, we calibrate the reform in the model to reproduce, over the long term, a growth miracle of the same magnitude as that experienced by postwar Japan. The reforms that eventually lead to the growth miracle give rise to an initial phase of transition, lasting roughly 3–6 years, during which the failure rate of plants rises 200–400 percent, and in which aggregate net investment in organization capital (measured at constant prices) rises between 300 and 500 percent above its steady-state level. Also, during this initial phase, measured output and aggregate productivity stagnate and physical investment falls. After 5–7 years, measured output and aggregate productivity begin to grow rapidly, physical investment rises substantially, and the growth miracle begins. Thus, in our stylized transition, a reform is followed by large increases in investment in organization capital over several years before measured output, productivity, and physical investment begin to grow.

In our model, it takes a number of years for the benefits of a stylized reform to show up in increased output and productivity. This initial stagnant phase occurs because new organizations must invest in their organization capital for several years before they can productively employ the physical capital and labor in the reformed economy. Even though our model is highly stylized, we see these results as a promising first step toward understanding actual transitions.

Section 2 of this paper presents the model of organization capital and industry evolution; Section 3 characterizes the equilibrium of the model; Section 4 discusses measurement of investment in organization capital and calibration; Section 5 presents our results; and Section 6 concludes the paper.

2 A Model of Organization Capital and Industry Evolution

Our model economy is described as follows. Time is discrete and is denoted by $t = 0, 1, 2, 3, \dots$. There are two types of agents in this economy: workers and managers. There exist a continuum of size one of workers and a continuum of size one of managers. Workers are each endowed with one unit of labor per period, which they supply inelastically. Workers are also endowed with the initial stock of physical capital and ownership of the plants that exist at date 0. They have preferences over consumption given by

$$(1) \quad \sum_{t=0}^{\infty} \beta^t \log(c_{wt}).$$

Given sequences of wages and intertemporal prices $\{w_t, p_t\}_{t=0}^{\infty}$, initial capital holdings k_0 , and initial value a_0 of the plants that exist at date 0, workers choose sequences of consumption $\{c_{wt}\}_{t=0}^{\infty}$ to maximize (1), subject to the budget constraint

$$(2) \quad \sum_{t=0}^{\infty} p_t c_{wt} \leq \sum_{t=0}^{\infty} p_t w_t + k_0 + a_0.$$

Managers are endowed with one unit of managerial time in each period. Managers have preferences over consumption given by

$$(3) \quad \sum_{t=0}^{\infty} \beta^t \log(c_{mt}).$$

Given sequences of managerial wages and intertemporal prices $\{w_{mt}, p_t\}_{t=0}^{\infty}$, managers choose consumption $\{c_{mt}\}_{t=0}^{\infty}$ to maximize (3), subject to the budget constraint

$$(4) \quad \sum_{t=0}^{\infty} p_t c_{mt} \leq \sum_{t=0}^{\infty} p_t w_{mt}.$$

Production in this economy is carried out in plants. At any date, a plant is characterized by its current productivity, A , and its age, s . The current productivity of a plant is given by the product $A = \tau B$, where τ is the quality of the blueprint used in the plant's construction and B is the current quality of its organization capital. To operate, a plant uses one unit of a manager's time, physical capital, and (workers') labor as variable inputs. If a plant with current productivity A operates with one manager, capital k , and labor l , it produces output

$$(5) \quad y = AF(k, l)^\nu$$

where the function F is linearly homogenous of degree 1 and $\nu \in (0, 1)$. Following Lucas (1978), we refer to ν as the “span of control” parameter of the plant's manager. The parameter ν may be interpreted more broadly as determining the slope of marginal cost within the plant. In what follows, we index plants by their productivity, A , and by their age, s .

Each plant that operates at date t experiences a stochastic innovation to the quality of its organization capital after it has finished current production. This innovation is denoted by ϵ_t , and the evolution of the plant's organization capital is given by $B_{t+1} = B_t \epsilon_t$. Thus a plant that had productivity A and operated at date t draws new productivity $A' = A\epsilon$ for period $t + 1$. The innovations ϵ_t are drawn independently across plants and across time. Innovations to the organization capital of a plant of age s at date t are drawn from an age-dependent distribution π_s . Such distributions are decreasing with age, in the sense of first-order stochastic dominance.

The timing of events at date t is as follows. For each plant that might operate at date t , the decision whether to operate or not is made at the beginning of the period. Plants that do not operate produce nothing; the organization capital in these plants is lost permanently. Plants of type (A, s) —which do operate—hire a manager, capital k_t , and labor l_t ; they produce output according to (5). After starting production, such plants draw innovation ϵ to their organization capital, with probabilities given by the cumulative distribution function

π_{s+1} . Thus a plant of type (A, s) that operates at t has stochastic type $(A\epsilon, s + 1)$ at the beginning of period $t + 1$.

Consider the process by which a new plant enters. Before a new plant can enter at date t , a manager must spend the period $t - 1$ adopting a blueprint for constructing the plant and preparing a plan for organizing the new plant. Blueprints adopted at date $t - 1$ embody the frontier of knowledge at that date. This frontier evolves exogenously, according to the increasing sequence $\{\tau_t\}_{t=0}^{\infty}$. The manager's plan for organizing the new plant determines the initial quality of its organization capital. At the end of period $t - 1$, this initial quality $B_0 (= \epsilon_0)$ is drawn with probabilities given by π_0 . The decision whether to construct and open this plant of type $(A_0 = \tau_{t-1}B_0, s = 0)$ or discard its plans is made at the beginning of period t . Plants that open at t hire a manager, capital, and labor; they produce according to (5), and they then experience an innovation to their organization capital as described above.

We assume that capital and labor are freely mobile across plants in each period. Thus, for any plant that operates at date t , the decision how much capital and labor to hire is static. Given wage rate w_t for labor, rental rate for capital r_t , and managerial wage w_{mt} , the operating plant chooses employment of capital and labor to maximize static returns:

$$(6) \quad \max_{k,l} AF(k, l)^\nu - r_t k - w_t l - w_{mt}.$$

Let $k_t(A)$ and $l_t(A)$ denote the solution to this problem. It is useful to define function $d_t(A)$ by

$$(7) \quad d_t(A) = AF(k_t(A), l_t(A))^\nu - r_t k_t(A) - w_t l_t(A).$$

The static returns to the owner of a plant of type (A, s) at t are given by $d_t(A) - w_{mt}$.

The decision whether to operate a plant or not is dynamic. Given sequences $\{\tau_t, w_t, r_t, w_{mt}, p_t\}_{t=0}^{\infty}$, this decision problem is described by the Bellman equation,

$$(8) \quad V_t(A, s) = \max [0, V_t^c(A, s)]$$

where

$$(9) \quad V_t^c(A, s) = d_t(A) - w_{mt} + \frac{p_{t+1}}{p_t} \int_{\epsilon} V_{t+1}(A\epsilon, s + 1) \pi_{s+1}(d\epsilon).$$

The value $V_t(A, s)$ is the expected discounted stream of returns to the owner of a plant of type (A, s) . This value is the maximum of the returns from closing the plant (0) and those from operating it. The term $V_t^c(A, s)$ is the expected discounted value of operating a plant of type (A, s) ; this value consists of current returns $d_t(A) - w_{mt}$ and the discounted value of expected future returns. The plant operates only if the expected returns $V_t^c(A, s)$ from operating it are nonnegative. Note that $V_t(A, s)$ is the price at which a plant of type (A, s) could be sold at date t .

The decision whether to hire a manager to prepare plans for a new plant is also dynamic. At date t , this decision is determined by the equation

$$(10) \quad V_t^0 = -w_{mt} + \frac{p_{t+1}}{p_t} \int_{\epsilon} V_{t+1}(\tau_t \epsilon, 0) \pi_0(d\epsilon).$$

The value V_t^0 is the expected stream of returns to the owner of a new plant, net the cost w_{mt} of paying a manager to prepare the plans for the plant. Plans for new plants are prepared only if the expected returns from these plans, V_t^0 , are nonnegative.

Let μ_t denote the distribution at date t of productivity and age across plants that might operate at that date, where $\mu_t(A, s)$ is the measure of plants of age s with productivity less than or equal to A . Let $\phi_t \geq 0$ denote the measure of managers preparing plans for new plants at t . Denote the measure of plants that operate at t by $\lambda_t(A, s)$. This measure is determined by the sign of the function $V_t^c(A, s)$ as follows. Let the operate decision be described by $z_t(A, s)$, with

$$(11) \quad z_t(A, s) = \begin{cases} 1 & \text{if } V_t^c(A, s) \geq 0 \\ 0 & \text{otherwise} \end{cases}.$$

Then

$$\lambda_t(A, s) = \int_{a \leq A} z_t(a, s) \mu_t(da, s).$$

For each plant that does operate, an innovation to its organization capital is drawn, and the distribution μ_{t+1} is determined from $\lambda_t, \phi_t, \{\pi_s\}$, and $\{\tau_t\}$ as follows:

$$(12) \quad \mu_{t+1}(A', s+1) = \int_A \pi_{s+1}(A'/A) \lambda_t(dA, s) \text{ for } s \geq 0$$

and

$$(13) \quad \mu_{t+1}(A', 0) = \pi_0(A'/\tau_t)\phi_t.$$

Letting k_t denote the aggregate physical capital stock, the resource constraints for physical capital and labor are

$$(14) \quad \sum_s \int_A k_t(A) \lambda_t(dA, s) = k_t$$

$$(15) \quad \sum_s \int_A l_t(A) \lambda_t(dA, s) = 1.$$

The physical capital stock evolves according to

$$(16) \quad k_{t+1} = y_t + (1 - \delta)k_t - c_{wt} - c_{mt}.$$

where y_t is defined by

$$(17) \quad y_t = \sum_s \int_A AF(k_t(A), l_t(A))^\nu \lambda_t(dA, s).$$

The resource constraint for managers is

$$(18) \quad \phi_t + \sum_s \int_A \lambda_t(dA, s) = 1.$$

Managers will be hired to prepare blueprints and plans for new plants only if $V_t^0 \geq 0$. Since there is free entry into the business of starting new plants, in equilibrium we require $V_t^0 \leq 0$. We summarize this condition as

$$(19) \quad V_t^0 \phi_t = 0.$$

In equilibrium, at date 0, the value of the worker's initial assets is given by

$$(20) \quad a_0 = \sum_s \int_A V_0(A, s) \mu_0(dA, s).$$

Given a sequence of frontier blueprints $\{\tau_t\}$, initial endowments k_0 and a_0 , and initial measure μ_0 , an *equilibrium* in this economy is a collection of sequences of consumption; aggregate capital $\{c_{mt}, c_{wt}, k_t\}$; allocations of capital and labor across plants $\{k_t(A), l_t(A)\}$; measures of operating plants, potentially operating plants, and managers preparing plans $\{\lambda_t, \mu_{t+1}, \phi_t\}$; value functions and operating decisions $\{d_t, V_t, V_t^c, V_t^0, z_t\}$; and prices $\{w_t, r_t, w_{mt}, p_t\}$, all of which satisfy (1)–(20).

3 Characterizing Equilibrium

In this section, we discuss some characteristics of equilibrium in a series of four propositions. In Proposition 1, we show that the size of a plant is proportional to its productivity, where the factor of proportionality depends on the span of control parameter ν . As a consequence of this proposition, data on the relative size of plants, together with a choice of ν , can be used to infer these plants' relative productivities. In Proposition 2 we show that the decision to operate a plant has a simple form: at each date, plants of a given age operate only if their productivity is above some age-specific cutoff point.

We then examine the steady-state growth path. In Proposition 3, we present an algorithm for constructing a steady-state growth path for this economy. As part of that construction, we characterize the equilibrium dynamics of individual plant size as well as the steady-state size-age distribution of plants. Finally, in Proposition 4, we show that data from a single steady state on the pattern of industry evolution do not identify the span of control parameter ν . In particular, we show that whatever equilibrium dynamics of individual plant size and steady-state size-age distribution of plants that can be obtained for *one* value of ν and shocks to productivity $\{\pi_s\}$ can be obtained with *every* value of $\nu \in (0, 1)$ with suitably adjusted distributions of shocks $\{\pi_s\}$. As a consequence of Proposition 4, in order to pin down the parameter ν we will need to use more data than the equilibrium dynamics of individual plant size and the steady-state size-age distribution of plants from a single economy.

Consider first the allocation of capital and labor across plants at any point in time. Since capital and labor are freely mobile across plants, the problem of allocating these factors across plants at date t is static. Given distribution λ_t of productivity across operating plants, aggregate capital k_t , and labor l_t , this allocation is as follows.

Proposition 1. In equilibrium, at each date t , the allocation of capital and labor at each plant is given by

$$(21) \quad k_t(A) = \left(\frac{A}{\bar{A}_t}\right)^{1/(1-\nu)} k_t/\psi_t$$

$$(22) \quad l_t(A) = \left(\frac{A}{\bar{A}_t}\right)^{1/(1-\nu)} l_t/\psi_t;$$

plant output and static returns are given by

$$(23) \quad y_t(A) = \left(\frac{A}{\bar{A}_t}\right)^{1/(1-\nu)} y_t/\psi_t$$

$$(24) \quad d_t(A) = (1-\nu) \left(\frac{A}{\bar{A}_t}\right)^{1/(1-\nu)} y_t/\psi_t$$

where y_t is aggregate output and is given by

$$(25) \quad y_t = \bar{A}_t \psi_t^{1-\nu} F(k_t, 1)^\nu;$$

and

$\psi_t = \sum_s \int_A \lambda_t(dA, s)$ is the measure of operating plants, with \bar{A}_t given by

$$(26) \quad \bar{A}_t = \left(\frac{\sum_s \int_A A^{1/(1-\nu)} \lambda_t(dA, s)}{\psi_t} \right)^{1-\nu}.$$

Proof. The first-order conditions from (6) include

$$\nu AF(k(A), l(A))^{\nu-1} F_k(k(A), l(A)) = r$$

$$\nu AF(k(A), l(A))^{\nu-1} F_l(k(A), l(A)) = w.$$

These equations, together with the assumption that $F(k, l)$ is linearly homogenous of degree one, imply that $k(A)/l(A)$ is equated across plants. Thus there exists a function $N_t(A)$ such that $(k_t(A), l_t(A)) = N_t(A)(k_t, 1)/\psi_t$, where $(k_t, 1)$ is the aggregate endowment of capital and labor at t and ψ_t is the measure of operating plants. The function $N_t(A)$, which satisfies the resource constraints (14) and (15), is given by

$$(27) \quad N_t(A) = \left(\frac{A}{\bar{A}_t}\right)^{1/(1-\nu)}.$$

Equations (23)–(25) are obtained directly through substitution. ■

Notice from (21), (22), and (23) that the fraction of aggregate capital and labor employed in a plant of type (A, s) , as well as the fraction of aggregate output produced by that plant at date t , is given by $N_t(A)$. We refer to $N_t(A)$ as the *size* of a plant of type (A, s) at date t . Equation (27) relates the size of a plant to its productivity. Clearly, more productive plants are larger. Notice that, given data on the size distribution of plants and a span of control parameter ν , from (27) we can derive information about the relative productivity of

plants of different sizes. If two plants are size N_1 and N_2 , then their productivities A_1 and A_2 satisfy

$$\left(\frac{A_1}{A_2}\right) = \left(\frac{N_1}{N_2}\right)^{1-\nu}.$$

The term \bar{A}_t is a geometric average of productivity across plants. From (25), this average \bar{A}_t is also the productivity of the average plant in the sense that, given aggregate endowment of factors k_t and l_t , an economy with ψ_t operating plants—all of which had productivity \bar{A}_t —would produce the same aggregate output y_t as an economy with distribution λ_t of plant productivities. Analogously, we define $\bar{A}_t(s)$ as the productivity of the average plant of age s as

$$\bar{A}_t(s) = \left(\frac{\int_A A^{1/(1-\nu)} \lambda_t(dA, s)}{\psi_t(s)}\right)^{1-\nu}$$

where $\psi_t(s) = \int_A \lambda_t(dA, s) / \psi_t$ is the fraction of operating plants of age s . It is easy to show that the total output of all plants of age s is given by

$$y_t(s) = \bar{A}_t(s) \psi_t(s)^{1-\nu} F(k_t(s), l_t(s))^\nu$$

where $k_t(s) = \int_A k_t(A) \lambda_t(dA, s)$ and $l_t(s) = \int_A l_t(A) \lambda_t(dA, s)$ are the average amount of capital and labor employed in plants of age s . Observe that

$$(28) \quad \frac{\bar{A}_t(s)}{\bar{A}_t} = \left(\frac{\int_A N_t(A) \lambda_t(dA, s)}{\psi_t(s)}\right)^{1-\nu}.$$

The term on the right side of equation (28) is the ratio of the fraction of labor employed in plants of age s to the fraction of plants that are age s .

Note that equation (28) implies that, given a choice of ν , the ratio of productivity in the average plant of age s to productivity in the average plant in the economy can be inferred from data on the ratio of the size of the average plant of age s to the size of the average plant in the economy. To make this connection between size and productivity concrete, consider what it implies about productivity in new plants in the U.S. data. Davis and Haltiwanger (1991) reported that, in the U.S. manufacturing sector, the fraction of labor employed in new plants is roughly 0.007 and the fraction of plants that are new each year is roughly 0.07. Thus these data indicate that the average new plant is only one-tenth the size of the average plant. If $\nu = 0.9$, then the average new plant is about 80 percent ($0.1^{0.1}$) as productive as

the average plant; if $\nu = 0.7$, then it is about $1/2$ ($0.1^{0.3}$) as productive as the average plant; while if $\nu = 0.5$, then it is about $1/3$ ($0.1^{0.5}$) as productive as the average plant.

We turn now to characterizing the dynamic decision of whether to operate a plant.

Proposition 2. At each date t , the solution to the decision problem of whether to operate a plant is summarized by an age-dependent cutoff rule $A_t^*(s)$. At date t , plants of age s with organization capital $A \geq A_t^*(s)$ continue in operation, and those with $A < A_t^*(s)$ close.

Proof. The result that the decision to operate a plant has the form of a cutoff rule follows from the result that the expected returns from operating a plant at date t , $V_t^c(A, s)$ are increasing in the plant's current productivity A for each age s . Clearly, current returns $d_t(A)$ are increasing in A . Also, by assumption, the distribution of a plant's productivity at $t + 1$ is increasing in its productivity at t , in the sense of first-order stochastic dominance. The result, that the value functions $V_{t+1}(A, s)$ are nondecreasing in A , is standard in this context. Thus $V_t^c(A, s)$ is increasing in A for each s . ■

Now consider the steady-state growth path. To ensure that our model has a balanced growth path, we assume that $F(k, l) = k^\theta l^{1-\theta}$.¹ We define a *steady-state growth path* in this economy as an equilibrium in which the quality of the best available blueprint τ_t and the productivity \bar{A}_t of the average plant grow at a constant rate $(1 + g_\tau)$; aggregate variables y_t, c_t, k_t, w_t , and w_{mt} grow at rate $(1 + g)$, where $(1 + g) = (1 + g_\tau)^{1/(1-\nu\theta)}$; variables ϕ_t, V_t^0 , and r_t are constant; and where the productivity-age distributions of plants satisfy the following: $\mu_{t+1}(A, s) = \mu_t(A/(1 + g_\tau), s)$ and $\lambda_{t+1}(A, s) = \lambda_t(A/(1 + g_\tau), s)$ for all t, A, s ; $V_{t+1}(A, s) = (1 + g)V_t(A/(1 + g_\tau), s)$, $d_{t+1}(A, s) = (1 + g)d_t(A/(1 + g_\tau), s)$; and $V_{t+1}^c(A, s) = (1 + g)V_t^c(A/(1 + g_\tau), s)$ for all t, A, s .

We now construct a steady-state growth path for this economy. We present an algorithm for constructing a candidate path and then, in Proposition 3, verify that the constructed path is an equilibrium. In our algorithm we find it convenient to change variables and characterize the steady-state exit decision as a cutoff rule in terms of plant *size* rather than plant *productivity*. This change of variables facilitates the proof of Proposition 4.

¹This assumption of Cobb-Douglas production is necessary for a steady-state growth path. Along a steady-state growth path, \bar{A} grows at constant rate $(1 + g_\tau)$, the capital-labor ratio k grows at rate $(1 + g)$, and $(1 + g_\tau)f((1 + g)k) = (1 + g)f(k)$, where $f(k) = F(k, 1)$. Thus $f(k)$ is homogenous of degree $x = 1 - \frac{\log(1 + g_\tau)}{\log(1 + g)}$. Since $f(\lambda k) = \lambda^x f(k)$, then $f(k1) = k^x f(1)$, so f is a power function and thus F is Cobb-Douglas.

The algorithm proceeds in 6 steps. Step 1 is to characterize the steady-state exit decision in terms of plant size. To that end we normalize $\tau_0 = 1$, let $\{\rho_s\}$ be the cumulative distribution functions of $\left(\frac{\epsilon}{1+g\tau}\right)^{1/(1-\nu)}$ induced by $\{\pi_s\}$, and consider the Bellman equation

$$(29) \quad W(n, s) = \max[0, W^c(n, s)]$$

$$W^c(n, s) = n - \omega_m + \beta \int_{\eta} W(n\eta, s+1) \rho_{s+1}(d\eta)$$

$$\omega_m = \beta \int_{\eta} W(\eta, 0) \rho_0(d\eta).$$

This equation will correspond to (8), except that here the state variable n is a scaled version of plant size, $\{\rho_s\}$ are distributions of shocks to plant size, and the value functions $W(n, s)$ and $W^c(n, s)$ correspond to $V_0(A^{(1-\nu)}, s)$ and $V_0^c(A^{(1-\nu)}, s)$ divided by a factor of proportionality. The steps 2–4 construct this factor of proportionality.

As step 2, we construct the steady-state *size-age* distribution as follows. From the solution of this Bellman equation we construct steady-state measures $M(n, s)$ and $\Lambda(n, s)$ over n and s , induced if we scale the measure of managers preparing plans for new plants each period to be one. [Think of M and Λ as corresponding to scaled versions of the measures μ and λ .] For $s = 0$, let $M(n, 0) = \rho_0(n)$. For $s \geq 0$, let

$$(30) \quad \zeta(n, s) = \begin{cases} 1 & \text{if } W^c(n, s) \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$\Lambda(n', s) = \int_{n \leq n'} \zeta(n, s) M(dn, s)$$

$$M(n', s+1) = \int_n \rho_{s+1}(n'/n) \Lambda(dn, s).$$

Here $\zeta(n, s)$ is the decision to operate the plant in terms of plant size and age. Define constants $L = \sum_s \int_n \Lambda(dn, s)$ and $\bar{N} = \sum_s \int_n n \Lambda(dn, s) / L$. Equilibrium plant size is given by $N = n / \bar{N}$. The steady-state *size-age* distribution of plants is then given by

$$\bar{\Lambda}(N, s) = \frac{\Lambda(n, s)}{1 + L}$$

where $N = n / \bar{N}$.

For step 3, we use these measures to construct the steady-state *productivity*-age distribution and the productivity path for the average plant as follows. Construct the following measures: $\phi_0 = \frac{1}{1+L}$; $\mu_0(A, s) = \frac{1}{1+L}M(A^{1/(1-\nu)}, s)$; $\lambda_0(A, s) = \frac{1}{1+L}\Lambda(A^{1/(1-\nu)}, s)$; and $\psi_0 = \frac{1}{1+L}L$. Use (26) to construct \bar{A}_0 from λ_0 and ψ_0 . Construct $\{\bar{A}_t, \mu_t, \lambda_t, \phi_t, \psi_t\}$ by $\bar{A}_t = (1 + g_\tau)^t \bar{A}_0$; $\mu_t(A, s) = \mu_0(A/(1 + g_\tau)^t, s)$; $\lambda_t(A, s) = \lambda_0(A/(1 + g_\tau)^t, s)$; and $\phi_t = \phi_0$, $\psi_t = \psi_0$.

As step 4, we construct sequences for aggregate output y_t , total consumption $c_t = c_{wt} + c_{mt}$, and the physical capital stock k_t , to be the steady-state growth path of a growth model in which the representative agent has preferences given by

$$\sum_t \beta^t \log(c_t)$$

and the technology is defined by (25) and (16) with sequences $\{\bar{A}_t, \psi_t\}$ constructed above. We construct $\{r_t, w_t\}$ from the marginal products of capital and labor as in Proposition 1. In particular, we set

$$r_t = \nu \bar{A}_t \psi_t^{1-\nu} F(k_t, 1)^{\nu-1} F_k(k_t, 1)$$

$$w_t = \nu \bar{A}_t \psi_t^{1-\nu} F(k_t, 1)^{\nu-1} F_l(k_t, 1).$$

In addition, we set the sequence of allocations of capital and labor across plants $\{k_t(A), l_t(A)\}$ as in Proposition 1.

These steps deliver the factor of proportionality required to construct the equilibrium value functions. Now define the constant

$$\Gamma = \frac{(1 - \nu)y_0}{\psi_0 \bar{A}_0^{1/(1-\nu)}}$$

and, as step 5, set the value functions and managerial wages as follows:

$$V_0(A, s) = \Gamma W(A^{1/(1-\nu)}, s)$$

$$V_0^c(A, s) = \Gamma W^c(A^{1/(1-\nu)}, s)$$

$$w_{m0} = \Gamma \omega_m$$

$$z_0(A, s) = \zeta(A^{1/(1-\nu)}, s)$$

with $V_t^0 = 0$, $V_t(A, s) = (1 + g)^t V_0(A/(1 + g_\tau)^t, s)$; $V_t^c(A, s) = (1 + g)^t V_0^c(A/(1 + g_\tau)^t, s)$; $z_t(A, s) = z_0(A/(1 + g_\tau)^t, s)$; and $w_{mt} = (1 + g)^t w_{m0}$.

Finally, as step 6, divide aggregate consumption between managers and workers in proportion to their wealth. Let $a_0 = \sum_s \int_A V_0(A, s) \mu_0(dA, s)$. Set $p_0 = 1$ and $p_t = (\beta/(1 + g))^t$, set $c_{mt} = c_t \sum_t p_t w_{mt} / (\sum_t p_t (w_{mt} + w_t) + k_0 + a_0)$, and $c_{wt} = c_t - c_{mt}$.

In Proposition 3, we verify that this candidate path is a steady-state growth path.

Proposition 3. Fix $\nu, g_\tau, \{\pi_s\}$, and normalize $\tau_0 = 1$. The following, constructed as above, then comprise a steady-state growth path of this economy: sequences of consumption and aggregate capital $\{c_{mt}, c_{wt}, k_t\}$; allocations of capital and labor across plants $\{k_t(A), l_t(A)\}$; measures of operating plants, potentially operating plants, and managers preparing plans $\{\lambda_t, \mu_{t+1}, \phi_t\}$; value functions $\{d_t, V_t, V_t^c, V_t^0, z_t\}$; and prices $\{w_t, r_t, w_{mt}, p_t\}$.

Proof. The key step of the proof is to show that the constructed value functions satisfy (8). Multiply (29) by Γ , substitute $A^{1/(1-\nu)}$ for n , and replace η with $\left(\frac{\epsilon}{1+g_\tau}\right)^{1/(1-\nu)}$ to get

$$\begin{aligned} \Gamma W(A^{1/(1-\nu)}, s) &= \max \left[0, \Gamma W^c(A^{1/(1-\nu)}, s) \right] \\ \Gamma W^c(A^{1/(1-\nu)}, s) &= \Gamma A^{1/(1-\nu)} - \Gamma z_m + \beta \int_\epsilon \Gamma W \left(\left(\frac{A\epsilon}{1+g_\tau} \right)^{1/(1-\nu)}, s+1 \right) \pi_{s+1}(d\epsilon) \\ \Gamma z_m &= \beta \int_\epsilon \Gamma W \left(\left(\frac{\epsilon}{1+g_\tau} \right)^{1/(1-\nu)}, 0 \right) \pi_0(d\epsilon). \end{aligned}$$

We can substitute our definition of $V_0(A, s) = \Gamma W(A^{1/(1-\nu)}, s)$ and $w_{m0} = \Gamma z_m$ into these equations to get

$$\begin{aligned} V_0(A, s) &= \max [0, V_0^c(A, s)] \\ (31) \quad V_0^c(A, s) &= \Gamma A^{1/(1-\nu)} - w_{m0} + \beta \int_\epsilon V_0(A\epsilon/(1 + g_\tau), s + 1) \pi_{s+1}(d\epsilon) \\ w_{m0} &= \beta \int_\epsilon V_0(\epsilon/(1 + g_\tau), s) \pi_0(d\epsilon). \end{aligned}$$

Finally, note from Proposition 1 that $d_0(A) = \Gamma A^{1/(1-\nu)}$. We can substitute this expression as well as $V_1(A, s) = (1 + g)V_0(A/(1 + g_\tau), s)$ and $\frac{p_{t+1}}{p_t} = \frac{\beta}{(1+g)}$ into (31) to verify that (8) is indeed satisfied.

Since the value functions and reward functions for subsequent dates are scaled versions of the value functions at date 0, they also satisfy (8), (9), and (10). The remaining equations (12)–(20) are satisfied by construction. ■

Consider the implications of this model for the distribution of plants by size and age along the steady-state growth path. Recall that the size of a plant of type (A, s) at t is given by $N_t(A) = (A/\bar{A}_t)^{1/(1-\nu)}$. Since \bar{A}_t grows at rate $(1 + g_\tau)$ and $\lambda_{t+1}(A, s) = \lambda_t(A/(1 + g_\tau), s)$ in the steady-state, the size-age distribution of plants is constant along the steady-state growth path. Previously we denoted that size-age distribution by $\bar{\Lambda}(N, s)$. In our next proposition we show that data on the size-age distribution of plants from a single steady-state growth path are not sufficient to pin down both the parameter ν and the distributions $\{\pi_s\}$. That is, given a choice of g_τ , there is a continuum of choices of ν and $\{\pi_s\}$, all of which generate the same steady-state size-age distribution of plants.

Proposition 4. Consider two economies that differ only in the parameters ν and $\{\pi_s\}$. Let $\bar{\Lambda}(N, s)$ be the steady-state size-age distribution of operating plants in the first economy, with ν and $\{\pi_s\}$, and let $\bar{\Lambda}'(N, s)$ be the steady-state size-age distribution of operating plants in the second, with ν' and $\{\pi'_s\}$. Let $\{\rho_s\}$ be the distributions of $\left(\frac{\epsilon}{1+g_\tau}\right)^{1/(1-\nu)}$ induced by $\{\pi_s\}$, and let $\{\rho'_s\}$ be the corresponding distributions implied by $\{\pi'_s\}$. If $\rho'_s = \rho_s$, for all s , then $\bar{\Lambda} = \bar{\Lambda}'$.

Proof. If $\rho'_s = \rho_s$ for all s , then value functions $W' = W$, $W^c = W^c$, and distributions $\Lambda' = \Lambda$. Thus $\bar{\Lambda}' = \bar{\Lambda}$. ■

We will calibrate our model to match data on the size-age distribution of plants in the United States. As a consequence of Proposition 4, we can rewrite our model so that the underlying shocks are to the *size* rather than the *productivity* of a plant. We calibrate our model to match data on the size-age distribution of plants by choosing the parameters of $\{\rho_s\}$ directly. We will use other data to pin down the parameters ν and $\{\pi_s\}$.

4 Measurement and Calibration

Investment in organization capital is not measured in the standard National Income and Product Accounts. In this section we propose a measure of the value of net investment in

organization capital in the context of our model using a method analogous to that used in the NIPA for measuring the value of net investment in physical capital. Our purpose in constructing this measure is to develop a yardstick for measuring the scale of investment in organization capital in the calibrated version of our model. In later sections we will see that the dynamics of this investment in organization capital in our model play an important role in shaping the dynamics of transition following reform.

In the data there are no direct measures of investment in organization capital. The approach we adopt is to use our model to construct prices and quantities of organization capital. Our model relates these prices and quantities to data on the size of organizations. We then use these data, together with our model, to construct the prices and quantities required to measure net investment in organization capital.

To measure the stock of organization capital at each date, we regard each type of plant indexed by productivity A and age s as a different capital good. In equilibrium, the *price* relative to output at date t for one plant (or one unit of organization capital) of type (A, s) , after current returns to the owner of the plant have been paid, is $q_t(A, s) = \frac{p_{t+1}}{p_t} V_{t+1}(A, s)$. The *quantity* of organization capital of type (A, s) is the number of plants of this type that might operate at $t+1$. The *current price* measure of net investment in organization capital of type (A, s) is the price $q_t(A, s)$ at date t of this type of organization capital times the change in the quantity of this type of capital from t to $t+1$. To measure aggregate investment in organization capital, we sum the values of investment in each type of capital. Thus the current price measure of aggregate net investment in organization capital in period t is

$$\sum_s \int_A q_t(A, s) (\mu_{t+1}(dA, s) - \mu_t(dA, s)).$$

To compare the value of investment in organization capital across different dates, we use a constant price measure of this investment. Letting date 0 be the base year, the *constant price* measure of net investment in organization capital is

$$\sum_s \int_A q_0(A, s) (\mu_{t+1}(dA, s) - \mu_t(dA, s)).$$

When applied to an economy in transition, in which the relative price of plants to consumption changes dramatically over time, this constant price measure has the standard index

number problems associated with the selection of the base-year prices. In order to ameliorate these index number problems, we choose to focus on the ratio of net investment in organization capital to the value of the stock of organization capital at constant prices, given by

$$\frac{\sum_s \int_A q_0(A, s)(\mu_{t+1}(dA, s) - \mu_t(dA, s))}{\sum_s \int_A q_0(A, s)\mu_{t+1}(dA, s)}$$

as a measure of the change in the aggregate quantity of investment in organization capital over the transition.

Now consider calibration of our model. The parameters we must choose are as follows. From agents' utility, we have the rate of time preference β . In production, we use $F(k, l) = k^\theta l^{(1-\theta)}$, so we now have the parameter θ , the span of control parameter ν , the depreciation rate δ , the growth rate g_τ of the best available technology τ_t , and the distributions of shocks to size $\{\rho_s\}$. We parameterize these distributions of shocks to size as follows. We assume that the innovations to size have a lognormal distribution, so that $\log(\eta_s) \sim N(m_s, \sigma_s)$. We choose the means and standard deviations of these distributions to be smoothly declining functions of s . In particular, we set $m_s = \gamma_0 - \gamma_1(1 - \exp(-s/\gamma_2))$ and $\sigma_s = \gamma_3 - \gamma_4(1 - \exp(-s/\gamma_5))$. These assumptions give us six parameters γ_i that must be selected.

To calibrate these parameters, we draw on "steady-state" observations from macro aggregates to determine preference parameter β , the depreciation rate δ , the capital share $\nu\theta$, and the growth rate of technology g_τ . We use "steady-state" observations from micro data on manufacturing plants in the United States to choose the parameters γ_i .

The choice of the macro parameters is standard. The time period of the model is one year. Along a steady-state growth path,

$$\frac{c_{t+1}}{\beta c_t} = \frac{(1+g)}{\beta} = \frac{p_t}{p_{t+1}} = \nu\theta \frac{y_t}{k_t} + (1-\delta)$$

and $g_\tau = (1+g)^{1-\nu\theta} - 1$. Using 1.02 as the growth rate of the economy and 1.0625 as the real interest rate gives $\beta = 0.96$ ($= 1.02/1.0625$). Using $\delta = 0.08$ as the depreciation rate and $k/y = 2$ as the physical capital-output ratio gives $\nu\theta = 0.285$ and $g_\tau = 0.0143$ ($= (1.02)^{0.715} - 1$).

Recall from (28) that the relative productivity of the average plant of age s is determined by ν and by the average size of plants of age s . This average size is the fraction of the

labor force employed in plants of age s divided by the fraction of plants of age s . We choose the parameters γ_i , describing the distributions of shocks to size $\{\rho_s\}$, so that the model matches data on the failure rates of plants of different age groups from Dunne, Roberts, and Samuelson (1989), Table 1, as well as data on the overall birth rate of plants and the fraction of the labor force employed in plants of different age groups from Davis and Haltiwanger (1992), Table 4. Note that data on the steady-state birth rate and the failure rates of plants of different ages is equivalent to data on the steady-state fractions of plants in each age group. Thus we calibrate our model so that, given a choice of the span of control parameter ν , its implications for the relative productivity of plants of age s are consistent with inferences drawn from data on the average size of plants of age s .

The statistics on employment shares and failure rates and the model's predictions for these statistics are presented in Table 1. The parameters γ_i governing the distributions of the shocks to size are given by $\gamma = (0.417, 0.461, 3.17, 0.28, 0.058, 5.96)$. We plot the means and standard deviations m_s and σ_s implied by our choice of parameters γ_i in Figure 1. These means and standard deviations have the scale of percentage changes in the size of a plant. Note that Table 1 follows our data sources and presents statistics from the model for selected age groups. We also find it useful to present in Figures 2–4 some other statistics from the model, namely the fraction of plants of each age ψ_s , the share of the labor force employed in plants of each age, and the average size of plants of each age. In Figure 4 the average size of a plant is normalized to one.

In the calibration, we have assumed that the distribution of shocks to size is lognormal. In order to match the data on employment shares and failure rates, we could have used a variety of other distributions. The simplest would be to let all plants of age s either draw size zero, and hence fail, or draw the average size in the data of plants of age s . Such a binomial distribution, however, would be grossly at odds with data on the distribution of growth rates of plants.

As a check of our choice of lognormal shocks to size, we examine some additional statistics on industry evolution generated from our model and compare them to similar statistics calculated by Davis and Haltiwanger (1992). We focus on total job reallocation and the histogram of plant employment growth rates unweighted and weighted by size. Davis and

Haltiwanger define total job reallocation between t and $t + 1$ is the sum of gross job creation and gross job destruction between those years. Gross job creation between years t and $t + 1$ is the total increase in employment in plants that expanded employment between t and $t + 1$. Gross job destruction between years t and $t + 1$ is the total decrease in employment in plants that contracted employment between t and $t + 1$. They report the average of total job reallocation over their sample to be 20.5 percent. The corresponding figure for our model is 21.3 percent. Note that, as a measure of the size-weighted sum of the absolute value of employment changes across plants, total job reallocation is analogous to the variance as a measure of the spread of the size-weighted distribution of employment changes across plants.

The second type of data they present is on the distribution of employment growth rates by plant. To incorporate consideration of plant births and deaths, Davis and Haltiwanger measure employment growth at a plant by the statistic

$$g_t = 2 \left(\frac{l_t - l_{t-1}}{l_t + l_{t-1}} \right).$$

This statistic ranges between -2 (for plants that die in t) to 2 (for plants that are born in t) and is close to the conventional measure of employment growth for small employment growth rates. Figure 5 reproduces the data histogram of plant employment growth rates presented in Figure 1a of Davis and Haltiwanger (1992). Observe in this histogram that the number of plant births is very close to the number of plant deaths. In Figure 6 we present the histogram of plant employment growth rates implied by our model. The principal difference between these two figures is that, in the data, the number of plants that have little or no change in employment is greater than in our model. In their Figure 1b, Davis and Haltiwanger also report the histogram of employment growth rates by plant, with the observations weighted by plant size. We reproduce this histogram in Figure 7. In comparing the weighted and unweighted histograms of the data, observe how the plants that are born or die tend to be smaller, while those that make only small changes in employment tend to be larger. The size-weighted histogram of employment growth rates by plant for our model is presented in Figure 8. As before, our model predicts fewer plants having small changes in employment than is observed in the data. Our model does reproduce the regularity that the plants that are born or die tend to be smaller, while the ones that make small changes in employment

tend to be larger.

Consider next the choice of the span of control parameter ν . Literally hundreds of studies have estimated production functions with micro data. These analyses incorporate a wide variety of assumptions about the form of the production technology, and draw on cross-sectional, panel, and time-series data from virtually every industry and developed country. Douglas (1967) and Walters (1963) survey a large number of studies. Recent work along these lines has been conducted by Bartelsman and Dhrymes (1992), Bahk and Gort (1993), and Baily, Hulten, and Campbell (1992). Atkeson, Khan, and Ohanian (1995) review this literature and present evidence, in the context of a model like ours, that $\nu \in (0.5, 0.85)$ is a reasonable range of estimates. In using our model for measurement and simulating transition, we consider values of $\nu \in (0.5, 0.9)$.

As we discussed in the previous section, Proposition 4 implies that the parameter ν is not pinned down by data on the size-age distribution from the steady state of a single economy. It is worth pointing out that the model's implications for the size-age distribution of plants across economies with different steady-state growth rates varies considerably, depending on the choice of ν . The growth rate of the frontier technology and the growth rate of the economy are related by $(1 + g_\tau) = (1 + g)^{1-\nu\theta}$, where $\nu\theta$ is the physical capital share. In our comparison across economies, we hold fixed the physical capital share $\nu\theta = 0.285$, the span of control parameter ν , and the distribution of shocks to organization capital $\{\pi_s\}$. We vary the growth rate of output g in the model by varying the growth rate g_τ of the frontier technology. From equation (29) it is clear that, holding fixed ν and the distribution of shocks to organization capital $\{\pi_s\}$, the decision to operate a plant of a given size depends on the growth rate of the frontier technology g_τ . We conduct this experiment using a wide range of values for the parameter ν .

Tables 2a and 2b present the model's implications for failure rates of plants of different ages, employment shares for plants of different ages for various growth rates g , and span of control parameters ν . We see that, in economies with high growth rates, plants have high failure rates and employment is concentrated in young plants, while the opposite is true in economies with low growth rates. The higher the span of control parameter ν , the more pronounced these features of the size-age distribution become. In Table 3, we show

the average size of new plants, relative to the average plant, against the growth rate of the economy for various values of ν . New plants are relatively larger in faster-growing economies. The higher ν is, the more pronounced this tendency becomes.

5 Organization Capital and Transition

In this section we use our model to measure investment in organization capital in the steady state and in the transition following a large-scale reform. We model reform as an increase in the growth rate of the quality of the technology τ_t used in the construction of new plants. In our transition we simulate the effects of an extremely beneficial reform. In particular, after the initial 6–7 years of transition, the model economy experiences sustained growth similar to the growth experienced in Japan from 1950 until the mid-1980s.

Consider first the scale of net investment in organization capital in the steady state. Table 4 presents the steady-state ratio of net investment in organization capital to output, measured in current prices for economies with the span of control parameter $\nu \in [0.5, 0.9]$. As Table 4 shows, this ratio is 20–22 percent of output for values of ν in the range above; our measure of the scale of investment in organization capital in the steady state is not very sensitive to the choice of the parameter ν . In addition, Table 4 presents the steady-state share of output paid to managers and the combined share of output paid to workers and managers for different values of ν . When $\nu = 0.85$ (not reported in the table), the share of output paid to workers and managers is two-thirds, which is consistent with the labor share observed in data. The combined share of output paid to workers and managers is not very sensitive to ν .

Next consider transition following reform. To simulate a transition, we parameterize the path of the frontier technology in the reforming country as follows. The best technology available for countries that do not reform is denoted by $\bar{\tau}_t$ and grows at rate g_τ . This domestic technology is behind the world’s frontier technology, denoted τ_{Wt} , which also grows at rate g_τ . Thus $\tau_{Wt} > \bar{\tau}_t$. During the transition in a country that undertakes reform, the domestic technology smoothly catches up to the world frontier. More precisely, let the reform occur

at date 0, and let the domestic frontier technology during transition be given by

$$\tau_t = (1 - \exp(-\alpha t))\tau_{Wt} + \exp(-\alpha t)\bar{\tau}_t.$$

Thus, during transition, at date t the domestic technology is a weighted average of the world frontier technology and the domestic technology for countries that do not reform. The weight on the world frontier is zero at $t = 0$ and approaches one at a rate determined by the parameter α .

To simulate a transition, we choose a value for the initial technology in the reforming economy relative to the world, $\bar{\tau}_0/\tau_{W0}$; a rate of technological convergence, α ; an initial value for the stock of physical capital, k_0 ; and an initial distribution of plants across productivity and age, $\mu_0(A, s)$. In the transitions reported below, we set $\bar{\tau}_0/\tau_{W0} = (1/6)^{(1-\nu\theta)}$ and set k_0, μ_0 , equal to their values on the steady-state growth path with technology $\tau_0 = \bar{\tau}$. We choose the convergence parameter $\alpha = 1/15$. At these choices, the country that is undertaking the reform starts off with output per capita at 1/6th the steady-state output of a country using the world's frontier technology. With $\nu = 0.8$, there is an initial period of 5–6 years in which output is below the pre-reform trend. After that, output in the reforming economy grows from 1/6 of the output of the world's leader to 3/4 of the output of the world's leader over a period of 35 years.

Figure 9 shows the path of output during transition of the reforming country relative to the pre-reform trend. With $\nu = 0.5$, we see that output does not begin to rise above its pre-reform trend for 8–9 years. With $\nu = 0.9$, it rises above the trend in only 4–5 years. In all cases, after an initial stagnant phase, output grows rapidly relative to the pre-reform trend. The length of that stagnant phase decreases as ν increases.

Figure 10 shows the path of gross physical investment relative to GDP, for various values of ν , in the reforming country during transition. In each case, investment in physical capital relative to output falls initially and then rises above its steady-state level. The size of the initial drop of the investment-output ratio becomes larger as ν becomes larger. The span of time that the investment-output ratio is below its steady-state level becomes longer as ν becomes smaller.

Figure 11 shows an index of the ratio of net investment in physical capital to the stock

of physical capital during transition. This index is normalized so that its steady-state value ($g = 0.02$) is one. In Figure 11, we see that, in the first few years of transition, there is a pause in net investment in physical capital and then a dramatic rise.

Figure 12 shows the ratio of net investment in organization capital to the value of the stock of organization capital at constant prices during transition, with the base-year prices being the prices from the year before the reform. As in Figure 11, we normalize the steady-state value of this ratio to one to highlight its change over time. For $\nu \in [0.5, 0.8]$, net investment in organization capital relative to the stock of organization capital rises by a factor of 3–5 times in the first 3–6 years of the transition. When $\nu \in [0.5, 0.8]$, the increase in the investment-capital ratio becomes larger as ν becomes larger.

In a number of respects, our model's implications for patterns of industry evolution in transition become implausible when ν is close to one. In this case, a plant with a slight productivity advantage over its competitors employs nearly all of the capital and labor in the economy. Moreover, small changes in the distribution of productivity across plants lead to drastic changes in the size distribution of plants. One aspect of this feature of our model is that, when $\nu = 0.9$, the ratio of investment in organization capital to the stock of organization capital oscillates during our stylized transition. (See Figure 13.)

Our explanation for the results reported in Figures 9–12 is as follows. Reform leads to a rapid inflow of new technologies. Agents form large numbers of new organizations to take advantage of these new technologies, and old organizations close as their managers are hired away by these new ones. This leads to a boom in investment in organization capital. Initially, these new organizations are not as productive as the ones they replaced because they have not yet built up their stock of organization capital. Thus, early on in the transition, aggregate productivity and output are stagnant and physical investment falls. As these new organizations acquire organization capital, productivity and output begin to grow and physical investment recovers.

Observe that the transition is more rapid and the surge of investment in organization capital is more pronounced when ν is closer to one. Intuitively, we can explain this: as ν becomes larger, diminishing returns set in more slowly, so the plants using the new technologies become larger relative to those using the old technologies. Since profits are proportional

to size, the value of a plant with new technology increases relative to the value of a plant with old technology. Thus, when ν becomes higher, old plants are replaced by new ones more quickly and the investment in organization capital is larger.

In comparing Figures 11 and 12, we see that the increase in investment in organization capital during transition comes several years before measured output, productivity, and physical investment begin to grow above their old, steady-state levels. Overall, it takes a number of years before the benefits of a stylized reform show up in increased output and productivity. This initial stagnant period occurs because new organizations must invest in their organization capital for several years before they can productively employ the physical capital and labor in the reformed economy. While investment in organization capital leads investment in physical capital for all $\nu \in [0.5, 0.8]$, the transition process is faster when ν is larger.

6 Conclusion

In this paper we have focused on measuring the scale of investment in organization capital, both in the steady state and in a stylized transition following reform. We have found that this investment is large in the steady state and rises dramatically during transition. These findings support the views of Lucas (1993) and Parente and Prescott (1994).

Our model abstracts from a variety of factors that would affect the nature of a transition. For example, we have assumed that physical capital and labor flow freely between plants, so we have abstracted from any aspect of plant-specific capital embodied in these factors. We have also abstracted from government policies, such as those toward closing old plants and letting new ones open, that would have an important impact on the nature of a transition. If the government were to undertake policies that slowed the pace of industry evolution, these policies would retard the formation and growth of new enterprises and thus slow the adoption of new technologies. Such policies would therefore delay the benefits of the reform. By contrast, if the government were to undertake policies that accelerated the rate at which agents closed existing enterprises and formed new ones, these could lead to the premature destruction of substantial amounts of the economy's organization capital and thus precipitate

large drops in aggregate output.

In our model, we have also assumed that there is no mechanism for transferring skills across organizations. To some extent, this assumption leads us to overestimate the investment in organization capital required in economies that are in the process of catching up with the leading economies of the world. One might suspect, for instance, that multinationals might be able to transfer organization capital through direct foreign investment. McDonald's, for example, is able to transfer considerable expertise across franchises by sending their employees to the firm's Hamburger University. More generally, the fact that new establishments owned by multi-plant firms are somewhat larger and have somewhat lower failure rates than plants established by single-plant firms (see Dunne, Roberts, and Samuelson 1989), may also reflect this transfer of skills across organizations. One interesting project would be to use data from the LRD on plants owned by multi-plant firms to shed some light on the possibilities for transferring organizational skills across plants.

We have presented a highly stylized model in order to isolate the role of organization capital and its impact on transition following reform. Before using this model to study transition episodes in specific countries, we would want to consider some of the other factors mentioned above. Nevertheless, we conjecture that more detailed analyses of reform will confirm the central role of organization capital in transition.

A Appendix: Principles for measuring net investment and depreciation

We have chosen one particular method for extending the National Income and Product Accounts to include investment in organization capital. We have found it useful to state abstractly the principles underlying this method and to work through several simple examples. Therefore we include this appendix for the interested reader.

We start with a capital theoretic framework. We call vectors k_t and n_t *inputs*, and vectors c_t and k_{t+1} *outputs*, with the technology described by $\{k_t, n_t, c_t, k_{t+1}\} \in Y_t$. In this framework, we distinguish two categories of outputs. The first category, c_t , includes the goods produced and consumed in this period. The second category, k_{t+1} , includes the (capital) goods used as inputs in the next period. We measure net investment as the value of the change in the stock of capital from t to $t+1$. Specifically, we define the (vector) quantity of net investment as

$$k_{t+1} - k_t.$$

Notice that net investment is zero if $k_{t+1} = k_t$; that is, net investment is zero if the vector of capital goods available to be used as inputs at $t+1$ is the same as it was at t . Let q_t be the price paid at t for one unit (a vector of ones) of capital delivered at $t+1$. Then our current price measure of net investment is

$$NI_t(t) = q_t \cdot (k_{t+1} - k_t).$$

Our constant price measure of net investment, using zero as a base year, is

$$NI_t(0) = q_0 \cdot (k_{t+1} - k_t).$$

We choose this approach, rather than measuring investment by the value of investment goods sold in the market, or by the cost of producing investment goods, so as to deal with cases

in which investment goods are jointly produced with consumption goods and not sold on the market. As we show in the examples below, the results from our approach coincide with results from these other approaches in the standard cases in which investment goods are not jointly produced and are sold in the market.

To measure depreciation, we distinguish capital goods of different ages. Let $k_t(s)$ be the vector of capital goods of age s and $q_t(s)$ be the corresponding price vector. Let $\tilde{k}_t(s) = k_t(s-1)$ for $s > 1$ and $\tilde{k}_t(0) = 0$. We define depreciation as

$$DEP_t = \sum_s q_t(s) \cdot (k_t(s) - \tilde{k}_t(s)).$$

Note that depreciation can be either positive or negative. We define gross investment as net investment plus depreciation.

Examples

We present three examples to demonstrate these principles for measuring investment. In the first two examples we measure investment in the one- and two-sector growth models. In the third example, we measure investment in a “tree economy” in which the production technology for capital is characterized by time-to-build.

One-Sector Growth Model: Capital goods are distinguished by age, with $k_t \in \mathfrak{R}^\infty$. The technology is described by $Y_t = \{k_t, n_t, c_t, k_{t+1} \mid (32), (33) \text{ hold}\}$

$$(32) \quad c_t + k_{t+1}(0) \leq A_t F(\sum_s (1-\delta)^s k_t(s), n_t)$$

$$(33) \quad k_{t+1}(s) = k_t(s-1) \quad s > 1.$$

In this model, $q_t(s) = (1-\delta)^s q_t(0)$ and $q_t(0) = 1$. Net investment is given by

$$NI_t = \sum_{s=0}^{\infty} (1-\delta)^s (k_{t+1}(s) - k_t(s))$$

which is equal to

$$NI_t = k_{t+1}(0) - \sum_{s=0}^{\infty} (1-\delta)^s \delta k_t(s).$$

Depreciation is given by

$$DEP_t = \sum_{s=0}^{\infty} (1-\delta)^s \delta k_t(s).$$

Thus gross investment is given by $k_{t+1}(0)$.

Two-Sector Growth Model: This is similar to the one-sector growth model, except that now we write the technology as follows:

$$(34) \quad c_t \leq A_t F\left(\sum_s (1-\delta)^s k_{1t}(s), n_{1t}\right)$$

$$(35) \quad k_{t+1}(0) \leq B_t G\left(\sum_s (1-\delta)^s k_{2t}(s), n_{2t}\right)$$

$$(36) \quad k_{1t}(s) + k_{2t}(s) = k_t(s)$$

$$(37) \quad n_{1t}(s) + n_{2t}(s) = n_t(s)$$

$$(38) \quad k_{t+1}(s) = k_t(s-1) \quad s > 1.$$

In this model, $q_t(s) = (1-\delta)^s q_t(0)$. Net investment in current prices is given by

$$q_t(0) \sum_{s=0}^{\infty} (1-\delta)^s (k_{t+1}(s) - k_t(s))$$

which is equal to

$$NI_t(t) = q_t(0)k_{t+1}(0) - q_t(0) \sum_{s=0}^{\infty} (1-\delta)^s \delta k_t(s).$$

Depreciation is given by

$$DEP_t = q_t(0) \sum_{s=0}^{\infty} (1-\delta)^s \delta k_t(s).$$

Thus gross investment is given by $q_t(0)k_{t+1}(0)$. Note that $q_t(0)$ is the price at t of one unit of capital of age 0 delivered at date $t+1$. To measure these quantities in constant prices, we would use price $q_0(0)$ from some base year in place of $q_t(0)$.

Let us note that we briefly considered an alternative measure of investment, namely the change in the value of the capital stock from t to $t+1$, here $q_{t+1} \cdot k_{t+1} - q_t \cdot k_t$. We chose not to use this measure because, in this two-sector growth model, neither gross investment nor net investment, measured in the standard way (as the value of investment goods sold, or by the costs of producing the investment goods), is equal to the change in the value of the capital stock. Investment measured in the standard way does not equal the change in the value of the capital stock because the relative price of existing capital to consumption changes over

time. However, the method for measuring investment that we propose is consistent with the standard measures of growth investment and net investment.

A Hardwood Forest: Consider an economy in which trees are planted, allowed to grow over several accounting periods, and then harvested. Let $k_t(s)$ be the stock of trees of age s at date t , so that $k_t \in \mathfrak{R}^S$, where S is the maximum age of a tree. Trees of age S can be cut down and consumed. Younger trees cannot be consumed. To plant a new tree takes one unit of labor. Cutting down trees and maintaining trees requires no labor. Let the production technology be described by

$$c_t \leq Ak_t(S)$$

$$k_{t+1}(s) = k_t(s-1) \quad \text{for } s \in [2, S]$$

$$k_{t+1}(1) \leq n_t.$$

Consider the entries in the NIPA for the life of one tree. Let $S = 4$. The tree is planted at $t = 0$. It ages in periods $t = 1, 2, 3$. It is harvested at $t = 4$. The sequence of labor inputs is $n_0 = 1$, otherwise $n_t = 0$. The sequence of increments to the capital stock is

$$k_0 = (0, 0, 0, 0)$$

$$k_1 = (1, 0, 0, 0)$$

$$k_2 = (0, 1, 0, 0)$$

$$k_3 = (0, 0, 1, 0)$$

$$k_4 = (0, 0, 0, 1)$$

$$k_5 = (0, 0, 0, 0).$$

The sequence of increments to consumption is given by $c_t = 0$ for $t = 0, 1, 2, 3$, and $c_4 = A$. The sequence of quantities of increments to net investment is given by $(1, 0, 0, 0)$, $(-1, 1, 0, 0)$, $(0, -1, 1, 0)$, $(0, 0, -1, 1)$, and $(0, 0, 0, -1)$. Let $q_t(s)$ be the price of trees of

different ages at t . Then the values of the increments to net investment at current prices are

$$NI_0 = q_0(1)$$

$$NI_1 = q_1(2) - q_1(1)$$

$$NI_2 = q_2(3) - q_2(2)$$

$$NI_3 = q_3(4) - q_3(3)$$

$$NI_4 = -q_4(4).$$

Depreciation is given by

$$DEP_0 = 0$$

$$DEP_1 = q_1(1) - q_1(2)$$

$$DEP_2 = q_2(2) - q_2(1)$$

$$DEP_3 = q_3(3) - q_3(4)$$

$$DEP_4 = q_4(4).$$

Thus the increments to gross investment are $q_0(1)$ at $t = 0$, otherwise zero. The increments to net product are given by the sequence $q_0(1)$, $q_1(2) - q_1(1)$, $q_2(3) - q_2(2)$, $q_3(4) - q_3(3)$, and $c_4 - q_4(4)$. The increments to gross product are given by $q_0(1)$, 0 , 0 , 0 , c_4 .

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Table 1

Plant Failure Rates

$g = 0.02$, all ν

Age (Years)

	1-5	6-10	11-15
DRS	.40	.30	.25
Model	.41	.28	.25

Employment Shares

$g = 0.02$, all ν

Age (Years)

	0	1	2	3	4-5	6-10	11-14	15+
DH	.8	1.8	1.5	1.5	4.5	14.3	11.0	64.5
Model	.9	1.2	1.5	1.8	4.3	12.2	11.4	66.6

Table 2a
Plant Failure Rates

$g = 0.01$

Age (Years)

	1-5	6-10	11-15
DRS	.40	.30	.25
$\nu = .9$	.07	.07	.06
$\nu = .8$	.41	.21	.16
$\nu = .7$	.41	.23	.18
$\nu = .5$	.41	.25	.21

Employment Shares

$g = 0.01$

Age (Years)

	0	1	2	3	4-5	6-10	11-14	15+
DH	.8	1.8	1.5	1.5	4.5	14.3	11.0	64.5
$\nu = .9$	.0	.0	.1	.1	.2	.8	1.2	97.5
$\nu = .8$	.2	.3	.4	.4	1.1	3.5	4.0	90.1
$\nu = .7$	.3	.5	.6	.7	1.8	5.5	5.9	84.8
$\nu = .5$	.5	.7	.9	1.1	2.6	7.7	7.9	78.6

Table 2b
Plant Failure Rates

$g = 0.05$

Age (Years)

	1-5	6-10	11-15
DRS	.40	.30	.25
$\nu = .9$	.66	.84	.91
$\nu = .8$	.49	.55	.63
$\nu = .7$	.45	.45	.49
$\nu = .5$	.43	.37	.38

Employment Shares

$g = 0.05$

Age (Years)

	0	1	2	3	4-5	6-10	11-14	15+
DH	.8	1.8	1.5	1.5	4.5	14.3	11.0	64.5
$\nu = .9$	11.9	13.7	14.2	13.4	21.6	22.1	2.9	.2
$\nu = .8$	5.6	7.1	8.2	8.9	17.6	31.6	13.7	7.3
$\nu = .7$	3.9	5.0	6.0	6.7	14.2	29.9	17.4	17.1
$\nu = .5$	2.6	3.4	4.2	4.8	10.6	25.2	18.0	31.3

Table 3
Average Size of New Plants
Relative to Average Size of All Plants

	$g = .01$	$g = .02$	$g = .05$
$\nu = .9$	.02	.11	.60
$\nu = .8$	.04	.11	.38
$\nu = .7$	.06	.11	.30
$\nu = .5$	.08	.11	.23

Table 4
Steady-State Net Investment
in Organization Capital
Ratio to Measured Output
Also Manager and Total Labor Shares

$g = 0.02$

	$\frac{Net\ Inv}{y}$	$\frac{w_m}{y}$	$\frac{w+w_m}{y}$
$\nu = .9$	.20	.06	.68
$\nu = .8$	.21	.13	.64
$\nu = .7$	.21	.19	.61
$\nu = .5$	.22	.32	.53

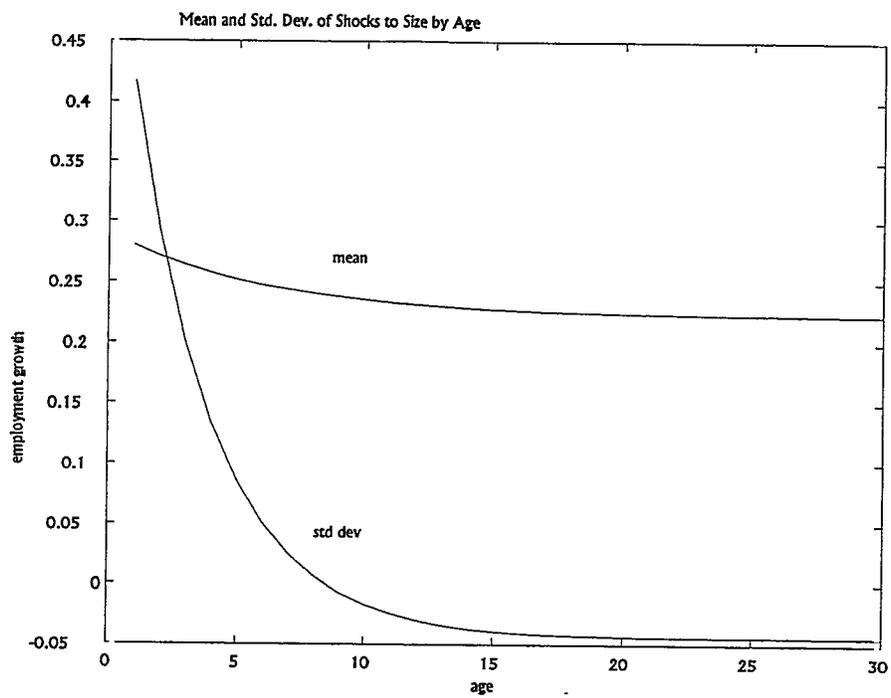


Figure 1: Mean and Standard Deviation of Shocks to Size

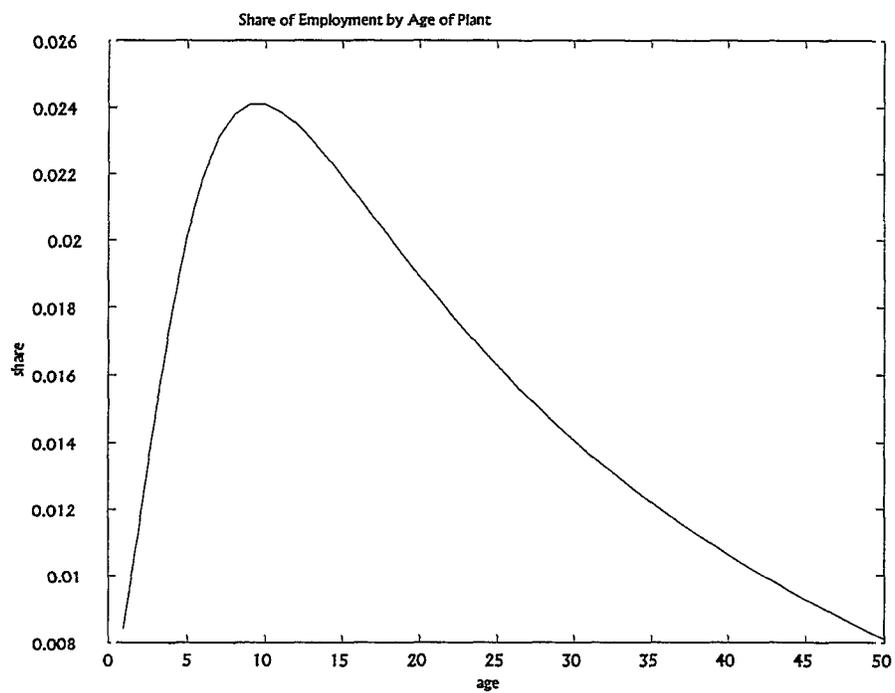


Figure 2: Model Share of Labor Force Employed in Plants of Age s

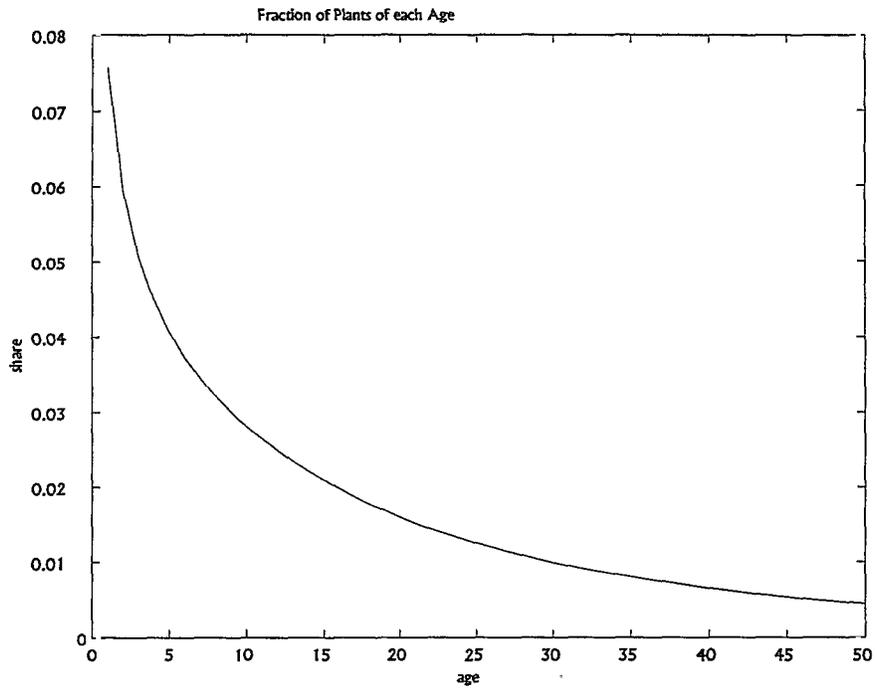


Figure 3: Model Fraction of Plants of Age s

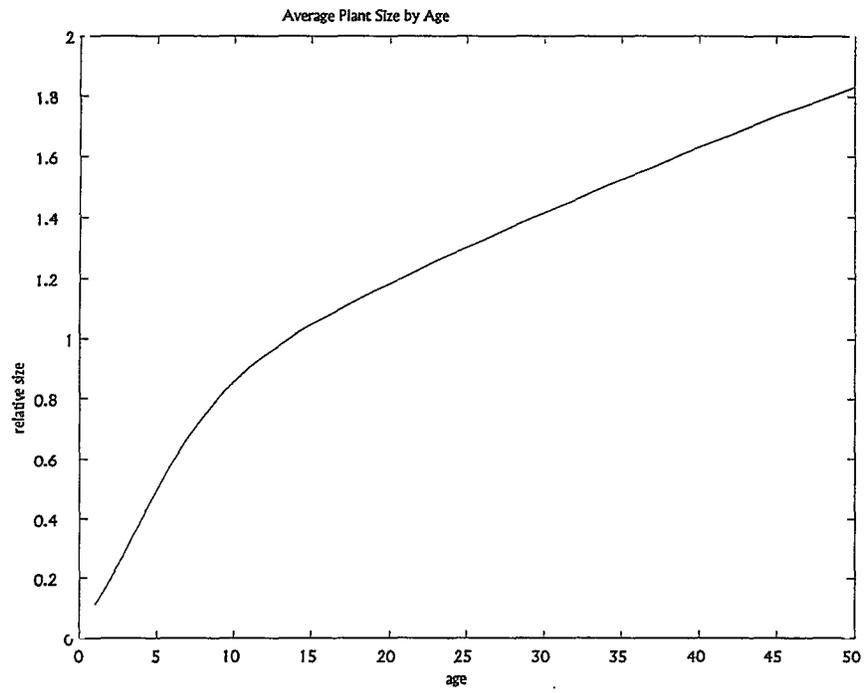


Figure 4: Model Average Size of Plants of Age s

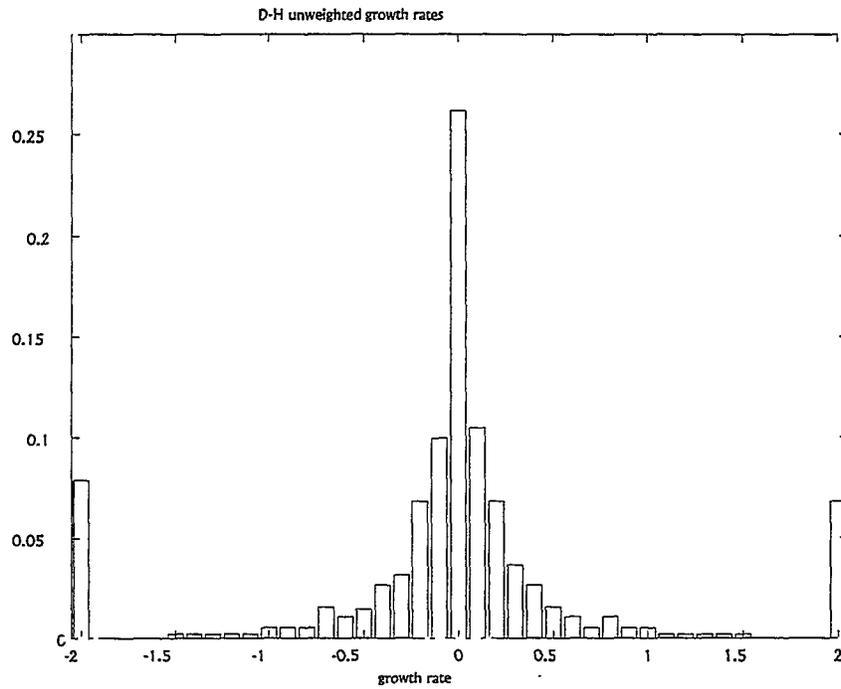


Figure 5: Data Histogram of Plant Employment Growth Rates from Davis and Haltiwanger (1992)

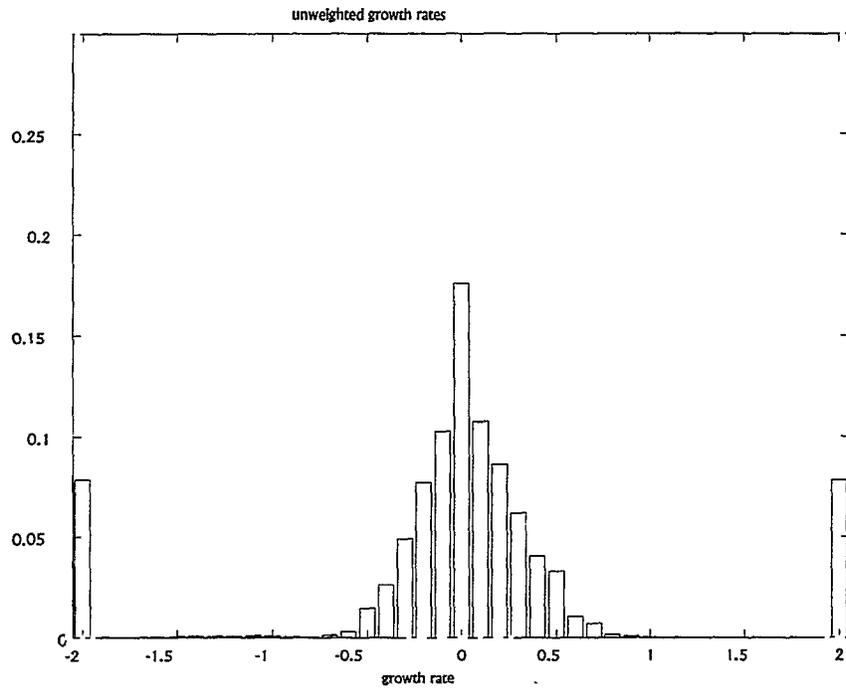


Figure 6: Model Histogram of Plant Employment Growth Rates

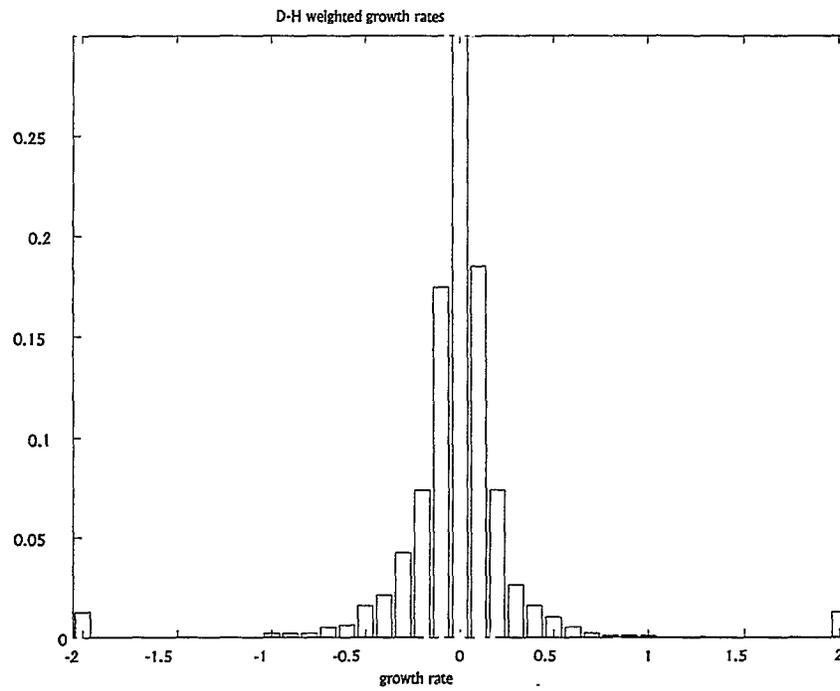


Figure 7: Data Histogram of Size-Weighted Plant Employment Growth Rates from Davis and Haltiwanger (1992)

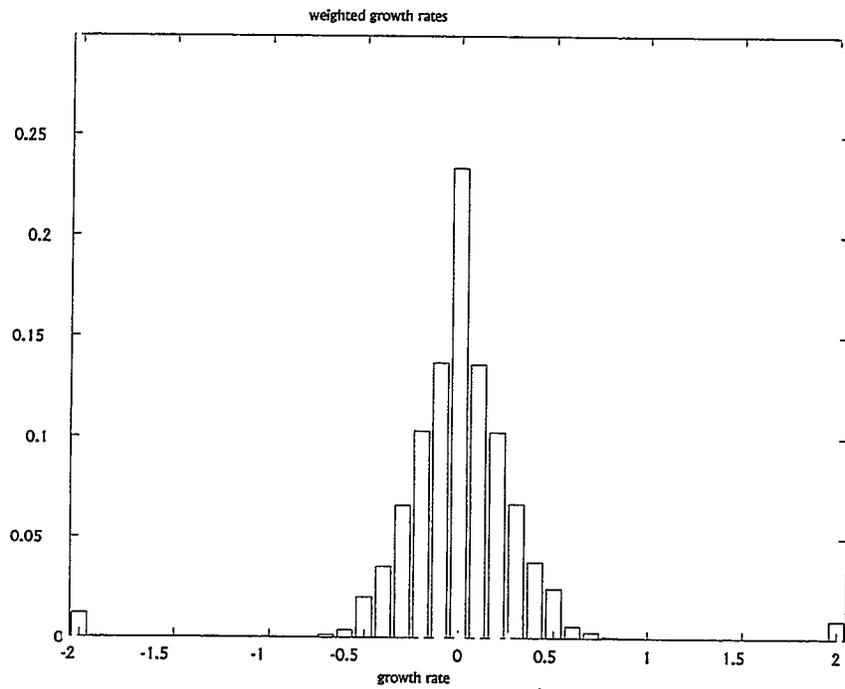


Figure 8: Model Histogram of Size-Weighted Plant Employment Growth Rates

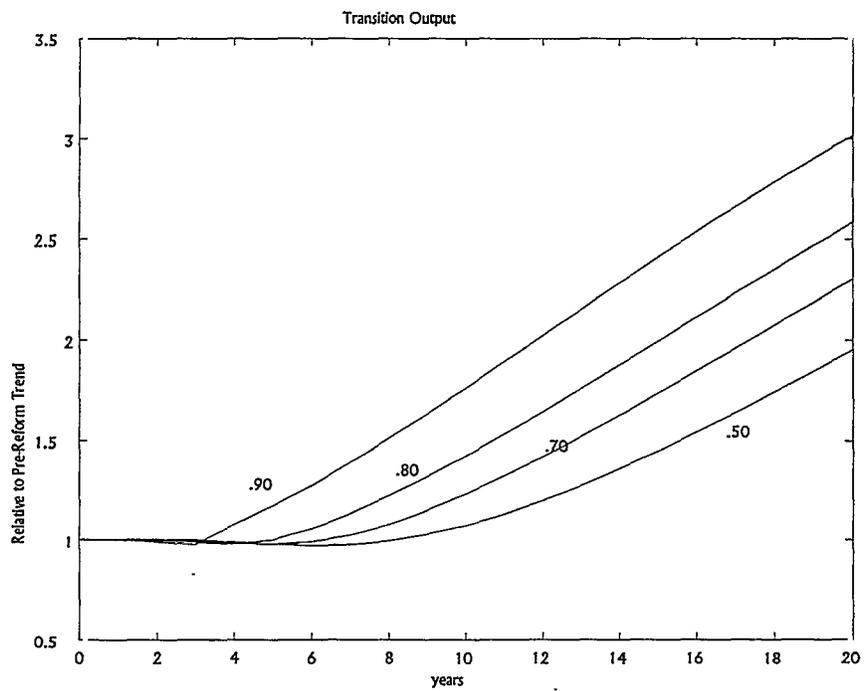


Figure 9: Model Transition Output over First 20 Years for Various ν

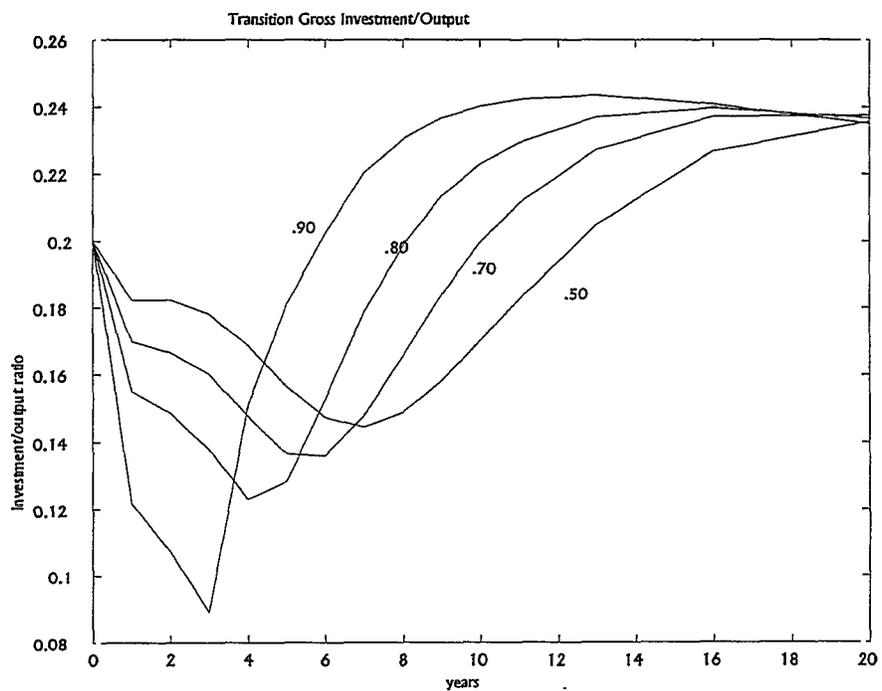


Figure 10: Model Gross Physical Investment-Output Ratio During First 20 Years of Transition for Various ν

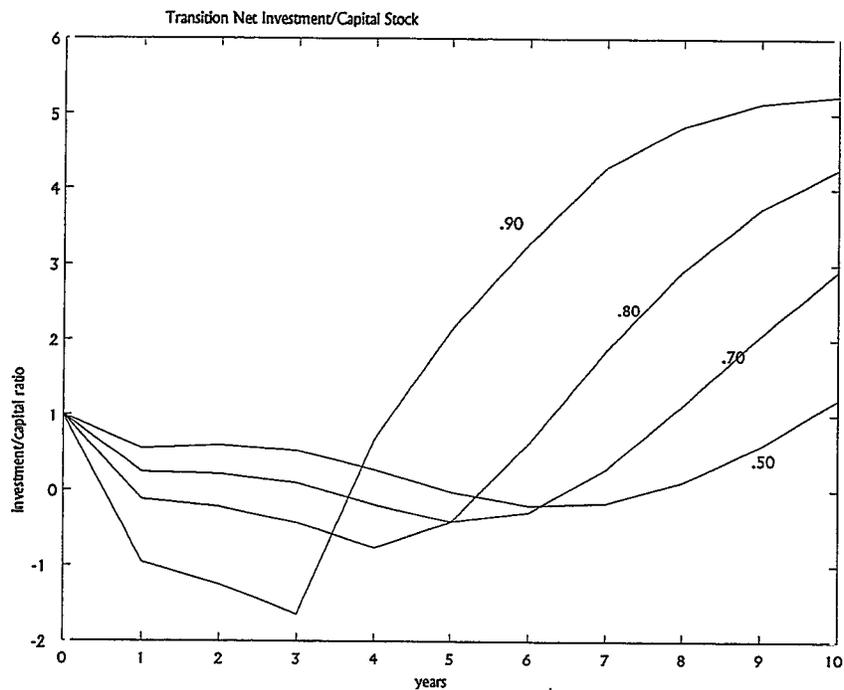


Figure 11: Model Net Physical Investment-Capital Ratio During First 20 Years of Transition for Various ν

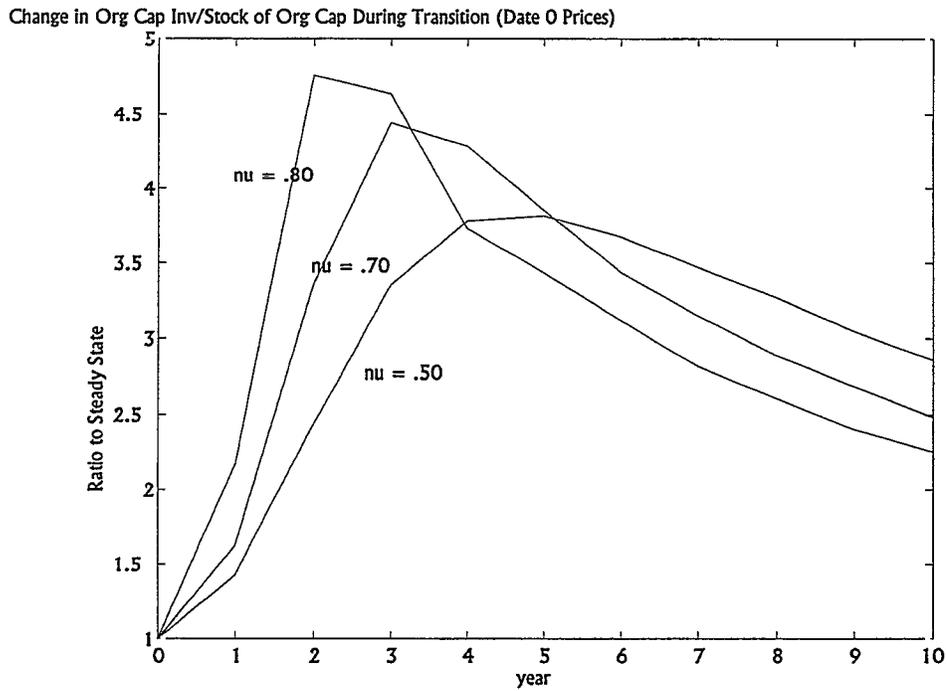


Figure 12: Transition Ratio of Net Investment in Organization Capital to Stock of Organization Capital $\nu = 0.5, 0.7, 0.8$

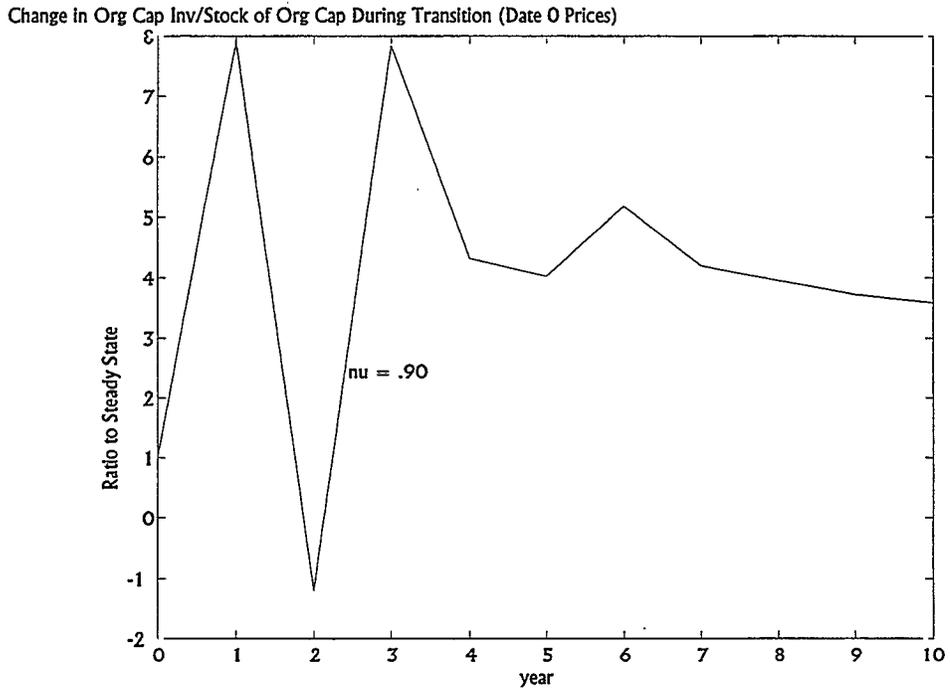


Figure 13: Transition Ratio of Net Investment in Organization Capital to Stock of Organization Capital $\nu = 0.9$