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Modeling and Measuring Organization Capital*

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ABSTRACT

Manufacturing plants have a clear life cycle: they are born small, grow substantially as they age, and eventually die. Economists have long thought that this life cycle is driven by the accumulation of plant-specific knowledge, here called *organization capital*. Theory suggests that where plants are in the life cycle determines the size of the payments, or *dividends,* plant owners receive from organization capital. These payments are compensation for the interest cost to plant owners of waiting for their plants to grow. We build a quantitative growth model of the life cycle of plants and use it, along with U.S. data, to infer the overall size of these payments. They turn out to be quite large—more than one-third the size of the payments plant owners receive from physical capital, net of new investment, and more than 40% of payments from all forms of intangible capital.

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Micro data on U.S. manufacturing plants reveal a clear life cycle: like their biological counterparts, manufacturing plants are born small, grow substantially as they age, and eventually die. (See, for example, Davis, Haltiwanger, and Schuh 1996.) Economists have long thought that this life cycle is driven by the accumulation of plant-specific knowledge, which we call *organization capital.* Theory suggests that where plants are in the life cycle determines the size of the payments, or *dividends,* plant owners receive from organization capital. These payments are compensation for the interest cost to plant owners of waiting for their plants to grow. Here we build a quantitative growth model of the life cycle of plants and use it, along with U.S. data, to measure the overall size of these payments. We find that the payments are quite large. In the model, the payments that owners receive from organization capital are more than one-third the size of the payments they receive from physical capital, net of new investment.

To give these numbers some additional context, we use McGrattan and Prescott's (forthcoming) procedure to infer the total payments owners of manufacturing firms receive from all intangible capital in the U.S. National Income and Product Accounts (NIPA). This procedure implies that such payments to intangible capital are about 8% of U.S. manufacturing output. In our model, the payments to organization capital alone are about 40% of those payments.

Our model of organization capital builds on the industry evolution models of Jovanovic (1982), Nelson and Winter (1982), and Hopenhayn and Rogerson (1993). We model the accumulation of organization capital at the plant level. Each plant is distinguished by its specific productivity and its age, and this pair of distinguishing features is what we consider the plant's organization capital. The specific productivity of a plant depends on the vintage of the plant's technology and its built-up stock of knowledge on how to use that technology. When new plants are built, their blueprints embody the best available, or *frontier,* technology, but they have little built-up knowledge. As a plant operates over time, its specific productivity grows stochastically at a rate that depends on the plant's age. We interpret this growth of a plant's specific productivity as arising from a stochastic learning process.

The basic mechanics of payments in our model is as follows. In the model, the owners of a plant pay fixed costs to start and operate the plant. In return, the owners collect variable profits less the fixed costs of operation as dividends over and above the rental payments for physical capital and labor. As the plant grows, so do these dividends; hence, the life cycle of plants corresponds to a *life cycle of dividends*: young plants tend to have low dividends; older plants, higher ones. In the model, an owner of an older plant has built up a type of intangible capital—organization capital—that entitles the owner to high dividends.

In the aggregate, what payments to organization capital should we expect to see in a steady state equilibrium? With free entry into the activity of starting plants, the present value of the stream of dividends to the owners of new plants is, of course, zero. At any particular time, however, the total payments owners receive from organization capital are the sum of the dividend payments to owners of plants of all ages in the cross section. If interest rates are positive and plants have the typical backloaded pattern of dividends over the life cycle, then we expect the dividends in the aggregate to be positive. These payments to owners compensate them for the interest cost of waiting for the plants to grow.

Our strategy for measuring the payments from organization capital is dictated by the mechanics of payments in the model. We build a quantitative model of the learning process that drives the life cycle of plants. The model then implies a corresponding life cycle of dividends. We infer the payments to organization capital by summing these implied dividends.

To quantify the learning process of plants in our model, we rely on the simple observation that the relative size of plants in the model is determined by their relative specific productivities. We calibrate the stochastic process by which plant productivity grows so that the model can reproduce panel data on employment, job creation, and job destruction in manufacturing plants of different ages in the U.S. economy.

When interpreted in the context of our model, these data on industry evolution indicate that learning is both prolonged and substantial. In the data, as a cohort of plants ages from newborn to 20 years old, for example, its share of the labor force grows by a factor of about seven. In our model, these data imply that the aggregate of specific productivities across a cohort of plants grows substantially for 20 years. More generally, our model replicates the patterns of plant birth, growth, and death in the U.S. economy and, hence, quantifies the accumulation of organization capital in this economy. With this quantitative model, we infer the payments to plant owners for organization capital directly rather than as a residual.

We model specific productivity as an exogenous stochastic process in a way similar to Hopenhayn and Rogerson's (1993). Our approach differs from that of a large literature which models specific productivity as endogenous. The main advantage of our approach is that it allows us to match the process for specific productivity directly to data on the growth process of plants. Moreover, we need not take a stand on whether this productivity is derived from active or passive learning, matching, or ongoing adoption of new technologies in existing plants.

The type of capital that we attempt to measure is one which has long been considered significant. At least as far back as Marshall (1930, Book iv, Chap. 13.I), economists have argued that organizations store and accumulate knowledge that affects their technology of production. This accumulated knowledge is a type of unmeasured capital distinct from the concepts of physical or human capital in the standard growth model. We think of this type of knowledge as driving the life cycle of plants and, hence, being the source of organization capital.

In terms of the literature, two broad themes have emerged since Marshall's (1930) work. One of those themes is that organization capital is a firm-specific or plant-specific capital good jointly produced with output and embodied in the organization itself. Rosen (1972), Ericson and Pakes (1995), and many others have developed models in which organization capital is acquired by endogenous learning-by-doing. We follow this theme and regard organization capital as embodied in the plant and as being jointly produced with measured output. In our model, this asset is transferable by selling the plant and payments to organization capital flow to owners of the plant.

A second broad theme in the literature is that organization capital is embodied in the firm's workers or in their matches to tasks within the firm. Jovanovic (1979), Prescott and Visscher (1980), Becker (1993), and others have developed explicit microeconomic models of this idea. Jovanovic and Moffit (1990), Topel (1991), and others have measured different aspects of firm-specific human capital. Models that follow this theme have at least some of the payments to organization capital flow to workers, depending on how owners and workers divide the match-specific quasi-rents. (See Rosen 1972 for a useful discussion of how different types of organization capital lead to different patterns of payments to owners and workers.)

In our model, all payments to organization capital flow to owners of plants, and our empirical strategy is designed to measure these payments. Developing a model that builds on the second theme, in which some of the payments to organization capital flow to workers, and using that model to measure such payments in the data is an interesting—and separate—exercise.

I. The Life Cycle of Plants and Organization Capital: An Illustration

Here we illustrate the connection between the life cycle of plants and the measurement of payments to organization capital in a steady state in a simplified version of our model. We then discuss some extensions.

In the model, time is discrete and is denoted by periods $t = 0, 1, 2, ...$ Production is carried out in plants. In any period, a plant is characterized by its age s, which determines its production function f_s. Each plant lives from age $s = 0$ through age $s = N$. The economy is in a steady state with overlapping generations of plants arranged into $N + 1$ cohorts, all of size 1.

To operate, a plant pays a fixed cost w_m to use one unit of a fixed factor of production and hires labor l at wage w as a variable input. Output in a plant of age s which hires l_s units of labor is $y_s = f_s(l_s)$. The decision of how much labor to hire in a plant of age s is static and given by

$$d_s = \max_l f_s(l) - wl,$$

where d_s is the *variable profits* of the plant. Employment in plants of cohort s is denoted by l_s, which solves $f'_s(l_s) = w$.

The *dividends* (or *profits*) to the owner of the plant are the variable profits minus the fixed cost. The economy has free entry in starting new plants. This free entry implies that the discounted value of dividends to the plant owner is zero, so that

$$\sum_{s=0}^{N} \left(\frac{1}{1+i}\right)^s (d_s - w_m) = 0, \tag{1}$$

where $1 + i$ is the real interest rate.

Here consumers and the definition of equilibrium are standard. In a steady state, the (gross) real interest rate $1+i$ is equal to $1/\beta$, where β is the consumer discount factor. The wage is such that the labor market-clearing condition $\sum_{s=0}^{N} l_s = 1$ holds, and the free entry condition (1) determines the price w_m of the fixed factor.

The characteristics of a plant's life cycle are determined by the dependence of the plant's production function on its age. For example, if the marginal product of labor increases with age, then older plants will be larger, in that they hire more labor than younger plants. This plant life cycle gives rise to a *life cycle of dividends,* defined as the time pattern of dividends $d_s - w_m$.

The *organization capital* of a plant is also indexed by its age s. The basic idea is that the owners of a plant of age s are entitled to the stream of dividends that remain after operating costs are paid, $\{d_{s+k} - w_m\}_{k=0}^{N-s}$. These are, in effect, payments to the owners for the knowledge built up in the plants over time. Clearly, free entry (1) implies that the value of the organization capital of a plant of age 0 is zero. But if dividends are backloaded, in the sense that d_s tends to rise with age, then the value of organization capital of plants of age $s > 0$ is typically positive.

Consider now the income and product accounts of this economy. Aggregate output is the sum of output across plants $\sum_{s=0}^{N} y_s$, while aggregate payments to labor and the fixed factor are also the relevant sum across plants $\sum_{s=0}^{N}(wl_s + w_m)$. Consumers, in their role as owners of plants, are paid an amount equal to output less variable and fixed costs, $\pi = \sum_{s=0}^{N} y_s - \sum_{s=0}^{N}(wl_s + w_m)$, which can be written as

$$\pi = \sum_{s=0}^{N}(d_s - w_m). \tag{2}$$

Note that π is the cross section aggregate amount of dividends. We interpret π as the payments to owners of plants as compensation for their organization capital, as measured in the income and product accounts of this economy.

Comparing (1) and (2) reveals that together the life cycle of dividends and the real interest rate determine the payments owners receive for organization capital. If either the real interest rate i is zero or dividends do not vary with age, then these payments π are zero. Alternatively, if the real interest rate is positive and dividends are backloaded, in that dividends d_s tend to grow with age, then these payments π are positive. Moreover, the more backloaded the dividends, the larger are the payments π.

A simple example illustrates the relationship between the backloading of dividends and the payments to organization capital. Let variable profits grow with plant age at rate $\gamma > 1$, so that $d_s = \gamma^s d_0$. Then the free entry condition (1) implies that the payments to the fixed factor are $w_m = d_0 \sum_{s=0}^{N} [\gamma/(1+i)]^s / \sum_{s=0}^{N} [1/(1+i)]^s$ and the payments to organization capital are $\pi = d_0 (N+1) \sum_{s=0}^{N} \gamma^s \omega_s$, where the weights ω_s are given by

$$\omega_s = \frac{1}{N+1} - \frac{[1/(1+i)]^s}{\sum_{s=0}^{N} [1/(1+i)]^s}.$$

These weights sum to zero and are monotonically increasing. Hence, payments to organization capital are increasing in the extent of backloading as indexed by γ.

Theoretically, at least, a perverse case may exist in which the dividends could be so frontloaded that payments to organization capital would actually be negative. If, however, we add to the model the possibility of *free exit,* so that plants can exit at no cost, then optimality by plants implies that, at each age n,

$$\sum_{s=n}^{N} \left(\frac{1}{1+i} \right)^s (d_s - w_m) \geq 0 \tag{3}$$

It is easy to show that under (3), the payments to organization capital (2) are always nonnegative, and as long as interest rates are positive, these payments are strictly positive whenever the dividend stream is not completely flat.[1]

Now we briefly describe several extensions of this simplified model.

First, in the simplified model we assumed that a fixed factor results in a fixed operating cost w_m. Adding an initial entry cost that simply gets subtracted from (1) and (2) is trivial. Doing so tends to increase the measured payments to organization capital in the cross section because it tends to increase the backloading of dividends.

Second, we have assumed perfect competition and that variable profits arise because the variable factors have diminishing returns. Alternatively, variable profits may arise because of imperfect competition. Below we show that a model with free entry and imperfect competition is isomorphic to what we have here.

Third, in our model, all payments to organization capital are payments to the owners of plants, while workers are simply paid their static marginal product. If we introduce dynamic employment features that break the relationship between current wages and current marginal product, then some of the payments to labor will also be payments to a different form of organization capital. Several researchers, including Jovanovic (1979) and Prescott and Visscher (1980), build models with these features. Quantifying the flow of payments to organization capital that are received by workers is an interesting and important exercise—but not one we are attempting.

Finally, in the next section, we extend the simple model to incorporate physical capital and uncertainty. We add these features so that we can compare the predictions of the model to the U.S. NIPA when we choose the model's parameters to reproduce U.S. data on the life cycle of plants.

II. A Model of Organization Capital

Now we set up our model of organization capital. We then show how to use data on the size of plants over the life cycle to infer the corresponding life cycle of plant dividends. Finally, we show how to extend the model to allow for imperfect competition.

A. The Setup

In our model, time is still discrete and denoted by periods $t = 0, 1, 2, \ldots$. The economy has a continuum of size 1 of households. Households have preferences over consumption given by $\sum_{t=0}^{\infty} \beta^t \log(c_t)$, where β is the discount factor. Each household consists of a worker and a manager, each of whom supplies one unit of labor inelastically. Households are also endowed with the initial stock of physical capital and ownership of the plants that exist in period 0. Households face sequences of wages for workers, wages for managers, and intertemporal prices $\{w_t, w_{mt}, p_t\}_{t=0}^{\infty}$; have initial capital holdings k_0; and own an initial asset value a_0 of the plants that exist in period 0. Given all that, households choose sequences of consumption $\{c_t\}_{t=0}^{\infty}$ to maximize utility subject to the budget constraint:

$$\sum_{t=0}^{\infty} p_t c_t \leq \sum_{t=0}^{\infty} p_t (w_t + w_{mt}) + k_0 + a_0. \tag{4}$$

Production in this economy is carried out in plants. In any period, a plant is characterized by its *specific productivity* A and its age s. To operate, a plant uses physical capital and (workers') labor as variable inputs and one unit of a manager's time as a fixed factor. If a plant with specific productivity A operates with one manager, capital k, and labor l, the plant produces output

$$y = zA^{1-\nu} F(k, l)^{\nu}, \tag{5}$$

where the function F is linearly homogeneous of degree 1 and the parameter $\nu \in (0, 1)$. The technology parameter z is common to all plants and grows at an exogenous rate. We call z *economy-wide productivity.* Following Lucas (1978, p. 511), we call ν the *span of control parameter* of a plant's manager. Here the parameter ν may be interpreted as determining the degree of diminishing returns at the plant level.

We refer to the pair (A, s) as a plant's *organization-specific capital,* or simply its *organization capital.* This pair summarizes the built-up expertise that distinguishes one plant from another.

The timing of events in period t is as follows. 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 with organization capital (A, s) that do operate, in contrast, hire a manager, capital k_t, and labor l_t and produce output according to (5). At the end of the period, operating plants draw independent innovations ϵ to their specific productivity, with probabilities given by age-dependent distributions $\{\pi_s\}$. Thus, a plant with organization capital (A, s) that operates in period t has stochastic organization capital $(A\epsilon, s + 1)$ at the beginning of period $t + 1$.

Consider the process by which a new plant enters the economy. Before a new plant can enter in period t, a manager must spend period $t - 1$ preparing and adopting a *blueprint* for constructing the plant that determines the plant's initial specific productivity τ_t. Blueprints adopted in period $t - 1$ embody the *frontier of knowledge* regarding the design of plants at that point in time. These blueprints evolve exogenously, according to the sequence $\{\tau_t\}_{t=0}^{\infty}$. Thus, a plant built in $t-1$ starts period t with initial specific productivity τ_t and organization capital $(A, s) = (\tau_t, 0)$. We refer to growth in τ_t as *embodied technical change.*

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

$$\max_{k,l} z_t A^{1-\nu} F(k,l)^{\nu} - r_t k - w_t l - w_{mt}. \tag{6}$$

Now define

$$d_t(A) = z_t A^{1-\nu} F\big(k_t(A), l_t(A)\big)^{\nu} - r_t k_t(A) - w_t l_t(A), \tag{7}$$

where $k_t(A)$ and $l_t(A)$ are the solutions to this problem. Then the *dividend* earned by the owner of a plant with organization capital (A, s) in t is given by $d_t(A)$ minus the fixed cost of hiring the manager w_{mt}. We refer to $d_t(A)$ as *variable profits.*

The decision whether or not to operate a plant is dynamic. This decision problem is described by the Bellman equation

$$V_t(A,s) = \max\left[0, d_t(A) - w_{mt} + \frac{p_{t+1}}{p_t}\int_{\epsilon} V_{t+1}(A\epsilon, s+1)\pi_{s+1}(d\epsilon)\right], \tag{8}$$

where the sequences $\{\tau_t, w_t, r_t, w_{mt}, p_t\}_{t=0}^{\infty}$ are given. The value $V_t(A, s)$ is the expected discounted stream of returns to the owner of a plant with organization capital (A, s). This value is the maximum of the returns from closing the plant and those from operating it. The second term on the right side of (8) is the expected discounted value of operating a plant of type (A, s). It consists of current returns $d_t(A) - w_{mt}$ and the discounted value of expected future returns $V_{t+1}(A, s)$. The plant operates only if the expected returns from operating it are nonnegative. We let the plant operating decision $x_t(A, s)$ equal one if the plant operates at t and zero otherwise.

The decision whether or not to hire a manager to prepare a blueprint for a new plant is also dynamic. In period t, this decision is determined by the equation

$$V_t^0 = -w_{mt} + \frac{p_{t+1}}{p_t} V_{t+1}(\tau_{t+1}, 0). \tag{9}$$

The value V_t^0 is the expected stream of returns to the owner of a new plant, net of the initial fixed cost w_{mt} of paying a manager to prepare the blueprint for the plant.

Let μ_t denote the distribution in period t of organization capital across plants that might operate in that period, 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 blueprints for new plants in t. Denote the measure of plants that operate in t by $\lambda_t(A, s)$. This measure is determined by μ_t and the operating decision $x_t(A, s)$ according to

$$\lambda_t(A, s) = \int_0^A x_t(a, s) \mu_t(da, s).$$

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

$$\mu_{t+1}(A', s+1) = \int_A \pi_{s+1}(A'/A) \lambda_t(dA, s) \tag{10}$$

for $s \geq 0$ and $\mu_{t+1}(\tau_{t+1}, 0) = \phi_t$.

Let k_t denote the aggregate physical capital stock. Then the resource constraints for physical capital and labor are $\sum_s \int_A k_t(A) \lambda_t(dA, s) = k_t$ and $\sum_s \int_A l_t(A) \lambda_t(dA, s) = 1$. The resource constraint for aggregate output is $c_t + k_{t+1} = y_t + (1 - \delta) k_t$, where y_t is defined by $y_t = z_t \sum_s \int_A A^{1-\nu} F\big(k_t(A), l_t(A)\big)^\nu \lambda_t(dA, s)$ and δ is the depreciation rate. The resource constraint for managers is $\phi_t + \sum_s \int_A \lambda_t(dA, s) = 1$.

Managers are hired to prepare blueprints for new plants only if $V_t^0 \geq 0$. Since there is free entry into the activity of starting new plants, in equilibrium we require that $V_t^0 \phi_t = 0$. Also, in equilibrium, $a_0 = \sum_s \int_A V_0(A, s) \mu_0(dA, s)$ is the value of the workers' initial assets.

Given a sequence of blueprints and economy-wide productivities $\{\tau_t, z_t\}$, initial endowments k_0 and a_0, and an initial measure μ_0, an *equilibrium* in this economy is a collection of sequences of consumption and aggregate capital $\{c_t, k_t\}$; allocations of capital and labor across plants $\{k_t(A), l_t(A)\}$; measures of operating plants, potentially operating plants, and managers preparing plans for plants $\left\{\lambda_t, \mu_{t+1}, \phi_t\right\}$; value functions and operating decisions $\{V_t, V_t^0, x_t\}$; and prices $\{w_t, r_t, w_{mt}, p_t\}$, all of which satisfy the above conditions.

B. Linking Plant Size and Plant Dividends

Now we link the variable profits $d_t(A)$ of a plant to the size of that plant as measured by its employment. We need this link because we calibrate the model to match U.S. data on the pattern of plant employment growth with age. We use this link as well to argue that our model will also match the evolution of variable profits of plants as they age. The corresponding life cycle of dividends is given by $d_t(A) - w_m$, where the fixed cost w_m is determined by the free entry condition.

Consider the allocation of capital and labor across plants at any point in time. Since capital and labor are freely mobile across plants, this allocation problem is static. For convenience, for a given distribution λ_t of organization capital, define

$$n_t(A) = \left(\frac{A}{\bar{A}_t}\right) \tag{11}$$

as the *size* of a plant of type (A, s) in period t, where $\bar{A}_t = \sum_s \int_A A\lambda_t(dA, s)$ is the aggregate of the specific productivities. The variable $n_t(A)$ measures the size of a plant in terms of its capital or labor or output, in that the equilibrium allocations are

$$k_t(A) = n_t(A)k_t,\ \ l_t(A) = n_t(A)l_t,\ \text{ and } y_t(A) = n_t(A)y_t, \tag{12}$$

where $y_t = z_t\bar{A}_t^{1-\nu}F(k_t, l_t)^\nu$ is aggregate output. To see this, note that since the production function F is linear-homogeneous of degree 1 and there is only one fixed factor, all operating plants in this economy use physical capital and labor in the same proportions. The proportions are those that satisfy the resource constraints for capital and labor.

The variable profits for a plant with organization capital (A, s) are

$$d_t(A) = (1-\nu)y_t(A) = (1-\nu)n_t(A)y_t. \tag{13}$$

Variable profits $d_t(A)$ minus managerial wages w_{mt} are the dividends earned on organization capital. Hence, (13) links the size of plants $n_t(A)$ with their dividends $d_t(A) - w_m$.

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 aggregate plant productivity $\bar{A}_t$ grow at a constant rate $1 + g_\tau$; the economy-wide level of productivity z_t grows at a constant rate $1 + g_z$; aggregate variables y_t, c_t, k_t, w_t, and w_{mt} grow at a rate $1 + g$, where $1 + g = [(1 + g_z)(1+g_\tau)^{1-\nu}]^{1/(1-\nu\alpha)}$; variables ϕ_t, V_t^0, and r_t are constant; the productivity-age distributions of plants satisfy $\mu_{t+1}(A, s) = \mu_t\big(A/(1+g_\tau), s\big)$ and $\lambda_{t+1}(A, s) = \lambda_t\big(A/(1+g_\tau), s\big)$ for all t, A, s; and $V_{t+1}(A, s) = (1+g)V_t\big((A/(1+g_\tau), s\big)$, $d_{t+1}(A, s) = (1+g)d_t\big(A/(1+g_\tau), s\big)$ for all t, A, s.

It is worth pointing out two features of the steady state of our economy. First, in this steady state, data on the size-age distribution of plants do not pin down the span of control parameter ν. Second, these data also do not pin down the extent to which technical change is embodied in blueprints or is economy-wide. (For details, see Atkeson and Kehoe 2003.)

C. Adding Imperfect Competition

So far we have assumed that the owners of plants earn variable profits because production at the plant level has diminishing returns, as indexed by ν. Here we add imperfect competition and show that these variable profits arise as well when plants face downward-sloping demand. The main effect of adding imperfect competition to the model is that it scales up the amount of variable profits in the economy; hence, it scales up the size of the payments owners receive from organization capital.

Here each plant produces a differentiated product which a competitive firm aggregates to produce a homogeneous final good. Each plant chooses its price and inputs to maximize profits given the downward-sloping demand from the firm that produces final goods.

The competitive final goods firm produces output according to

$$y_t = \left[\sum_s \int_A y_t(A)^\theta \lambda_t(dA, s)\right]^{1/\theta}$$

and has a static demand function $y_t(A) = p_t(A)^{-1/(1-\theta)} y_t$. Note that we have imposed symmetry, in that all operating plants with the same A choose the same output and set the same price. We have also normalized the price of the final good to be 1.

We adjust the notation of a plant's production function so that, in equilibrium, its variable profits are given by (13). Accordingly, we let the production function of a plant be given by

$$y_t(A) = z_t^{1/\theta} A_t^{(1-\gamma\theta)/\theta} F\big(k_t(A), l_t(A)\big)^{\gamma}.$$

It is easy to show that the static maximization problem of a plant is given by (6) and (7) with $\nu = \gamma\theta$. Note that ν is the product of the diminishing returns parameter γ from production and the parameter θ which governs the slope of the demand function. (Specifically, θ is the inverse of the equilibrium markup of price over marginal cost.) With this modification, the rest of the analysis is identical.

III. Calibration and Measurement

Now we bring the appropriate U.S. data into the model so as to infer the size of the payments to organization capital in the U.S. economy.

The model's macro parameters are taken either directly from McGrattan and Prescott (forthcoming) or from our application of their method to the manufacturing sector as described in our Appendix A.

To match the model to observations, we follow McGrattan and Prescott (forthcoming) and introduce a corporate profits tax τ_c. We assume that this tax is levied on corporate profits measured as sales less compensation of employees and the depreciation of physical capital $(y_t - w_t l_t - w_{mt} - \delta k_t)$. We assume that these corporate tax revenues are rebated as a lump-sum payment to workers. Accordingly, the workers' Euler equation for physical capital implies that

$$\frac{c_{t+1}}{\beta c_t} = \frac{1+g}{\beta} = 1 + i = (1-\tau_c)(\nu\alpha\frac{y_{t+1}}{k_{t+1}} - \delta) + 1. \tag{14}$$

We use the values of $\beta = .98$, $g = 2.02\%$, and $i = 4.1\%$ from McGrattan and Prescott (forthcoming). Using the method we describe in Appendix A, we find that the depreciation rate $\delta = 5.5\%$; the capital share $k/y = 1.46$; the corporate tax rate $\tau_c = 48.1\%$; and, hence, $\nu\alpha = 19.9\%$. Note that τ_c is computed by applying Poterba's (1998) method to manufacturing. As Poterba finds, the τ_c we measure is higher than the statutory corporate tax rate because τ_c includes the sum of the corporate profit and property tax burdens.

Now consider the parameter $\nu = \gamma\theta$. Based on the work of Basu and Fernald (1995), Basu (1996), and Basu and Kimball (1997), we choose $\theta = .9$, which implies a markup of 11 percent and an elasticity of demand of 10. The parameter γ measures the degree of diminishing returns in variable factors at the plant level. Hundreds of studies have used micro data to estimate production functions. 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 (1948) and Walters (1963) survey many studies. More recent work along these lines has also been done by Baily, Hulten, and Campbell (1992); Bahk and Gort (1993); Olley and Pakes (1996); and Bartelsman and Dhrymes (1998). From a survey of this work, we argue that in the context of a model like ours, $\gamma = .95$ is a reasonable value for this parameter. Using that value gives $\nu = .85$, which is consistent with the discussion of Atkeson, Khan, and Ohanian (1996).

In parameterizing the distributions of shocks to specific productivity, we assume that these shocks to size have a lognormal distribution, so that $\log \epsilon_s \sim N(m_s, \sigma_s^2)$. We choose the means m_s and standard deviations σ_s of these distributions to be smoothly declining functions of s. In particular, we set $m_s = \kappa_1 + \kappa_2(\frac{S-s}{S})^2$ for $s \leq S$ and $m_s = \kappa_1$ otherwise and $\sigma_s = \kappa_3 + \kappa_4(\frac{S-s}{S})^2$ for $s \leq S$ and $\sigma_s = \kappa_3$ otherwise. With this parameterization, the shocks for plants of age S or older are drawn from a single distribution. Thus, shocks to plant-specific productivity are parameterized by $\{\kappa_i\}_{i=1}^4$ and age S.

We choose the parameters governing these shocks so that the model matches data on the fraction of the labor force employed in plants of different age groups, as well as data on job creation and destruction in plants of different age groups, from the 1988 panel of the U.S. Census Bureau's Longitudinal Research Database (the LRD).[2] We choose the data from this panel because it has the most extensive breakdown of plants by age. We think of choosing these statistics as analogous to choosing means and variances of shocks to productivity.

More formally, Davis, Haltiwanger, and Schuh (1996) define the following statistics. *Employment* in a plant in year t is $(l_t + l_{t-1})/2$, where l_t is the labor force in year t. *Job creation* in a plant in year t is $l_t - l_{t-1}$ if $l_t \geq l_{t-1}$ and zero otherwise. *Job destruction* in a plant in year t is $l_{t-1} - l_t$ if $l_t \leq l_{t-1}$ and zero otherwise. In Figure 1, we report these three statistics for U.S. manufacturing plants in 1988 for all plants in each age category relative to the total employment in all plants. This gives us a total of 26 statistics from the data that we use to summarize the life cycle of plants.

We set the parameter $S = 100$ and choose the four parameters $\{\kappa_i\}_{i=1}^4$ to minimize the sum of the squared errors between the corresponding 26 statistics computed from the model and those in the data. The resulting model statistics are also plotted in Figure 1. In Figure 2, we plot the means and standard deviations of shocks to the log of the size of plants, m_s and σ_s. The parameters that generate these shocks are $S = 100$, $\kappa_1 = -.1139, \kappa_2 = .1741$, $\kappa_3 = .1945$, and $\kappa_4 = .0006$.

In the top panel of Figure 1, we see that our model matches the U.S. employment shares fairly well. In the middle and bottom panels, we see that our model implies a bit more job creation and destruction than are observed in the U.S. data. This is reflected in the implied statistics for the data and the model: the overall job creation and destruction rates are 8.3% and 8.4% for the data and 10.2% and 10.2% for the model. Note, however, that in annual data during 1972–93, the standard deviation of the overall job creation and destruction rates are 2.0 and 2.7. (See Davis, Haltiwanger, and Schuh 1996.) Hence, our model's overall job creation and destruction rates are within one standard deviation of the observed time series fluctuations in these rates.

IV. Industry Evolution in the Steady State

We have calibrated our model to U.S. data on employment shares and job creation and destruction for plants in various age groups. Here we compare the implications of our calibrated model to other important features of U.S. data on the birth, growth, and death of plants. We find that our model approximately captures most of these features. Hence, we argue that the model replicates the basic patterns of the accumulation of organization capital in the data.

Specifically, we compare our model to U.S. data on job destruction in failing plants, the distribution of employment growth rates by plants, and the distribution of labor and capital productivity in plants by age. We think of the data on job destruction in failing plants as measuring the failure rate of plants, in contrast to job destruction, which is the death rate of jobs. The data on the distribution of plant growth rates are a check on our assumption that the shocks to size are normally distributed. The data on plant productivity are a check on our model's implications that there is no systematic relation between plant age and capital and labor productivity.

First consider plant failure rates. In Figure 3, we show the rate of job destruction in failing plants by age group for the model and the U.S. data. For each age group, job destruction in failing plants is the ratio of employment in plants that fail in that age group to total employment. This ratio has the interpretation of a size-weighted failure rate of plants. Overall, total job destruction in plants that fail is 3.1% in the model and 2.2% in the data. In this sense, the size-weighted failure rate is higher in the model than in the data. This result is consistent with our earlier finding that the overall job destruction rate is higher in the model than in the data.

Next consider the distribution of plant growth rates. In Figure 4, we show the distribution of plant-level job creation and destruction in the model and the data. In this figure, we divide plants into ten groups, based on the plants' growth rate of employment (measured here by $G = (l_t - l_{t-1})/l_{t-1}$), and show the fraction of total job creation (when G is positive) and the fraction of total job destruction (when G is negative) accounted for by plants in each group.[3] For the data, we again draw on the work of Davis, Haltiwanger, and Schuh (1996). In their data, a substantial amount of job creation comes from continuing plants that more than double in size (15.3%), and a substantial amount of job destruction comes from continuing plants that more than halve in size (18.4%). In our model with normally distributed shocks to size, shocks this large are more than three standard deviations from the mean and occur with extremely low probability. In order to match these extreme observations, we would need fatter-tailed distributions for the shocks.

Finally, consider the distributions of labor and capital productivity across plants by size and age. Our model predicts that at each point in time, both of these measures of productivity are constant across plants. This implication follows immediately from our assumption that the production function is Cobb-Douglas. To see this, note that (12) implies that $y_t(A)/l_t(A) = y_t/l_t$ and $y_t(A)/k_t(A) = y_t/k_t$. For the data, Bartelsman and Dhrymes (1998) report, for a large sample of U.S. manufacturing plants drawn from the LRD, a geometric weighted average of capital and labor productivity

$$(\frac{y_{it}}{k_{it}})^{\alpha}(\frac{y_{it}}{l_{it}})^{1-\alpha}$$

by age group where the weights α are obtained from a regression of outputs on inputs. In Figure 5, we report the Bartelsman and Dhrymes values for this measure by age groups. Although Bartelsman and Dhrymes find substantial variations in average productivity across individual plants in their data, Figure 5 demonstrates that they find no systematic relation between the average productivity of a plant and its age.

Jensen, McGuckin, and Stiroh (2001) find similar results in the data. They study labor productivity measured as value added per hour worked in a more extensive sample of U.S. manufacturing plants, also drawn from the LRD. They note there is extensive variation in labor productivity across individual plants in their sample. When productivity is averaged across plants in a cohort, however, there seems to be no systematic relationship between labor productivity and age. Indeed, Jensen, McGuckin, and Stiroh report that after about 5–10 years, all cohorts of surviving plants have similar productivity levels.

V. Measurement of Organization Capital

Here we report our model's measure of the share of output that is paid to owners of organization capital and the value of that capital relative to the value of physical capital. We also compare these findings to corresponding data for the U.S. manufacturing sector.

Recall that in our model, aggregate output is given by

$$y = z\bar{A}^{1-\nu}k^{\nu\alpha}l^{\nu(1-\alpha)}. \tag{15}$$

This output is distributed among four factors: physical capital, workers, managers, and organization capital. The share of output paid to owners of physical capital is $\nu\alpha$; to workers, $\nu(1-\alpha)$; and to managers, w_m/y; and the rest is paid to owners of organization capital. We have calibrated the physical capital share in the model to match that in the data, so that $\nu\alpha = 19.9\%$. The share of output paid to labor is the sum of the shares paid to workers and managers. With a span of control parameter $\nu = .85$, the share paid to workers is $\nu(1-\alpha) = 65.1\%$.

We now use the model to compute the division of the remaining 15% of output into the share paid to managers and the share paid to owners of organization capital. In the model, the managerial wage is determined by the condition that there be zero profits to starting new plants, namely, that $w_{mt} = \frac{1}{1+i_t} V_{t+1}(\tau_{t+1}, 0)$.

In Table 1, we report these shares for the data and the model, with several values for ν. We start our discussion with $\nu = .85$. With our calibration, 11.7% of output is paid to managers, so that the share paid to labor is 76.8%, and the share paid to owners of organization capital is 3.3%. In comparison, the shares in the data are 72.2% for labor and 8.0% for intangible capital. Our model thus accounts for about 41% (3.3/8.0) of the payments to owners of intangible capital in manufacturing. Since the shares in our model must sum to 1, the remainder of the payments to owners of intangible capital, 4.7% $(8.0 - 3.3)$, must show up in another share. Since we calibrate the model to match the physical capital share of 19.9%, the remainder shows up as payments to managers and is thus added to the labor share, raising the total labor share in the model above that observed in the data.

The payments to owners of organization capital represent the payments net of the cost of the owners' investment in this capital. To put these payments in context, it is useful to compare them to the net payments that owners of physical capital receive after deducting the cost of new investment, that is, $rk - x$. In Table 1, we see that in the model the payments to owners of organization capital are 37% (3.3/8.9) of the net payments to owners of physical capital.

Most of the parameters of our model are well-measured. One has greater uncertainty than the rest, however: the span of control parameter ν. How sensitive are our findings to this parameter? Consider raising ν from .85 to .90 or lowering it to .80 and, in each case, adjusting α so that the physical capital share $\nu\alpha$ is unchanged at 19.9%. With these changes in the span of control parameter—the results of which are also shown in Table 1—the share of output paid to owners of organization capital falls from 3.3% to 2.2% or rises to 4.4%. Again, because the factor shares sum to 1, the remainder of the unaccounted-for output is attributed to labor.

More generally, we can show that the payments to owners of organization capital relative to the sum of the payments to both owners of organization capital and managers is independent of ν. To see this, note from (8) and (9) that the value functions and managerial wages are homogeneous of degree 1 in $1 - \nu$. Thus, if we have two economies with the same shocks to plant size, one having span of control parameter ν, managerial wages w_{mt}, and value function $V_t(A, s)$ and the other having span of control parameter $\tilde{\nu}$, managerial wages $\tilde{w}_{mt}$, and value functions $\tilde{V}_t(A, s)$, then

$$\frac{\tilde{V}_t(A,s)}{1-\tilde{\nu}} = \frac{V_t(A,s)}{1-\nu}$$

and $\tilde{w}_{mt}/(1-\tilde{\nu}) = w_{mt}/(1-\nu)$. Since $1-\nu$ is the sum of managerial wages and payments to owners of organization capital, the result follows.

In Table 1, we see that of the 15% share paid to owners of organization capital and managers together (with $\nu = .85$), organization capital owners get roughly one-quarter of the share and managers get the rest. Given the above result, this relation holds for all ν. Hence, for any ν, the organization capital share is roughly $(1-\nu)/4$, and the managerial share is roughly $3(1-\nu)/4$.

VI. Conclusion

We have proposed a quantitative model of the life cycle of plants and demonstrated how it can be used to measure the payments to owners of a specific form of intangible capital directly, rather than as a residual. The key idea behind our model is that the owners of plants are making expenditures early in a plant's life cycle in order to reap dividends in the future. We think of the activity of starting a new plant as a project of investing in organization capital that typically yields a backloaded life cycle pattern of dividends. Because these dividends are backloaded, the aggregate payments to owners of plants for compensation for the investment in organization capital are positive. These payments correspond to the interest cost to plant owners of waiting for their plants to grow.

Notes

[1]Note that free exit for $n = N$ and $n = N - 1$ implies that $d_N - w_m \geq 0$ and

$$d_{N-1} - w_m + (\frac{1}{1+i})(d_N - w_m) \geq 0.$$

Since $d_N - w_m \geq (d_N - w_m)/(1+i) > 0$ we have that

$$d_{N-1} - w_m + d_N - w_m \geq 0.$$

The result then follows by induction.

[2]Here and throughout, our microeconomic data are taken from the U.S. Census Bureau's 1988 Longitudinal Research Database (LRD) on U.S. manufacturing plants. These data are broken down by crude age categories. In Figures 1 and 3, we use data from the 1988 panel of the LRD obtained from the computer disk that accompanies Davis, Haltiwanger, and Schuh's (1996) book; these data are also available from Haltiwanger's Web site: http://www.bsos.umd.edu/econ/haltiwanger/.

[3]For each plant, let $G_{it} = (l_{it} - l_{it-1})/l_{it-1}$. Then, for example, for the category $[0, 10\%]$, the statistic plotted is

$$\frac{\sum_{\{i|G_{it}\in[0,.1]\}} l_{it} - l_{it-1}}{\sum_i \max\{0, l_{it} - l_{it-1}\}}.$$

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Appendix A

Payments to Owners of Intangible Capital in the U.S. NIPA

1. *Method*

McGrattan and Prescott (forthcoming) present a method for computing the amount of payments to owners of intangible capital in the U.S. corporate sector. Here we apply their method to the U.S. manufacturing sector. We first describe a stripped-down version of the accounting procedure, to give the basic idea, and then we go through the details of the actual calculation.

In the general procedure, net product for a given sector is given by

$$\textit{Net Product} = (r - \delta)k + wl + \pi, \tag{A1}$$

where $(r - \delta)k$ is the rental payments to measured capital net of depreciation, wl is the compensation of labor, and π is payments to intangible capital. Data on net product NP, depreciation δk, measured capital k, and compensation of labor wl can be obtained from the U.S. National Income and Product Accounts (NIPA) produced by the U.S. Department of Commerce (various dates). The basic idea of the McGrattan and Prescott procedure is to impute the rental rate r using the equilibrium condition that the return on measured capital $(r - \delta)$ should equal the return i on other investments. Once this return i is specified, payments to owners of intangible capital π can be computed from (A1).

When we apply this basic idea to the manufacturing sector and use the NIPA, we must take into consideration sales taxes and corporate income taxes. First, since the value added is measured at consumer prices, it exceeds the value added of producers by the amount of sales taxes. Hence, we rewrite (A1) as

$$\textit{Net Product} - \textit{Sales Taxes} = (r - \delta)k + wl + \pi. \tag{A2}$$

Next, when corporate income is taxed, the equilibrium condition is that the return on capital after corporate taxes $(1-\tau)(r-\delta)$ is equal to the return on other investments i, so that

$$i = (1-\tau)(r-\delta). \tag{A3}$$

Payments to intangible capital are, thus,

$$\pi = \textit{Net Product} - \textit{Sales Taxes} - \frac{i}{1-\tau}k - wl. \tag{A4}$$

We measure the variables in (A4) as follows. Net product (NP) is measured as the value added in manufacturing (VA) less consumption of fixed capital (CFC), which corresponds to δk.

The NIPA has no direct data on sales taxes paid in manufacturing. We use the method of Poterba (1998) to infer these taxes. The NIPA reports the taxes on production and imports less subsidies, which we denote by IT; it is essentially the sum of sales taxes (ST) and property taxes (PT). We estimate property taxes and then subtract them from IT to get our measure of sales taxes. Property taxes are estimated by multiplying the ratio of tangible assets in manufacturing to that of the economy as a whole by state and local property tax receipts ($SLPTR$). Here, as Poterba (1998) argues, property taxes are treated as part of the value added at producer prices, but sales taxes are not.

We measure wl as the sum of compensation of employees (CE) plus three-quarters of proprietors income (PI). We include a portion of proprietor's income in our measure of wl in order to capture payments to proprietors that are compensation for their labor input rather than their ownership of the means of production.

The variable k which corresponds to measured capital is constructed as the sum

$$k = k_{ES} + k_{Inv} + k_{Land},$$

where k_{ES} represents fixed capital, the sum of equipment and structures; k_{Inv}, the stock of inventories; and k_{Land}, the stock of land.

To compute the tax rate τ, we apply to manufacturing a procedure similar to that of Poterba (1998) and McGrattan and Prescott (forthcoming). We take the sum of corporate profit taxes (CT), property taxes (PT), and business current transfers (BT) and divide it by the sum of net product minus sales taxes (ST) minus wl, so that

$$\tau = \frac{CT + PT + BT}{NP - ST - wl}.$$

Here we are viewing business transfers as an implicit tax. These transfers consist primarily of liability payments for personal injury, corporate gifts to nonprofit institutions, and taxes paid by domestic corporations to foreign governments. (See Seskin and Parker 1998.) We view these transfers as a cost of doing business that owners of plants must pay.

The variable i is the real interest rate, which we take from McGrattan and Prescott (forthcoming). As McGrattan and Prescott have argued, this rate is the real interest rate after personal income taxes that a household would receive on an investment. In Appendix B in Atkeson and Kehoe 2003, we give a rationale for why this is the appropriate rate of return.

2. *Results*

We report the results of our decomposition in the familiar units of percentages of the value added, at producer prices (given by the value added at purchaser prices minus sales taxes). To translate our results into these units, we add depreciation to both sides of (A2) to get

$$\textit{Value Added – Sales Taxes} = \delta k + (r - \delta)k + wl + \pi.$$

We find the following average shares over the period 1950–2001: δk, 8.0%; $(r - \delta)k$, 11.9%; wl, 72.2%; and π, 8.0%. In addition, the payments net of investment to owners of physical capital are $rk - x$, where x denotes investment. We find that $rk - x$ relative to value added is 8.9% over the period 1950–2001. From these results, we find that, on average, the payments to owners of intangible capital, π, are 110% of the payments to owners of physical capital, net of investment, $rk - x$.

Notice that the NIPA only measures the total payments to owners of plants for both physical capital and intangible capital. The McGrattan–Prescott method decomposes these payments into the payments for physical capital and a residual, the latter of which is the payments to intangible capital. The decomposition is done by using separate data to set the real interest rate i used to compute the payments to physical capital. There is a large literature, including work by Poterba (1998) and Larkins (2000), which investigates a logically separate question. That work supposes that there are no payments to intangible capital and finds the rate of return on physical capital which would lead the payments to physical capital to exhaust the total payments to owners of plants for both physical capital and intangible capital. Hall (2003) performs a related calculation. He assumes that, on average, there are no payments to intangible capital, and he finds the rental rate on physical capital which would lead the payments to physical capital to exhaust the total payments to owners of plants for both physical capital and intangible capital.

In our calculation of the tax rate τ, we have followed Poterba (1998) in using a measure of the average tax burden on corporations. Some provisions, such as accelerated depreciation and the tax deductibility of interest payments, can lead the marginal tax burden to be lower than the average tax burden. If we redid our calculations with a lower tax rate for τ in (A4), we would obviously increase the McGrattan–Prescott measure of the payments to owners of intangible capital. In this sense, the McGrattan–Prescott measure of those payments is a conservative one.

3. *Sources*

The following variables come from various issues of the "Gross Domestic Product by Industry Accounts" provided by the U.S. Commerce Department's Bureau of Economic Analysis (BEA): value added in manufacturing VA, taxes on production and imports less subsidies IT, business current transfer payments BT, and compensation of employees CE. (The data come from two spreadsheets, GDPbyInd_VA_NAICS.xls and GDPbyInd_VA_SIC.xls.)

The following variables come from various issues of the U.S. Commerce Department's NIPA: state and local property tax receipts ($SLPTR$) from Table 3.3, proprietor's income (PI) from Table 6.12, and inventories (k_{Inv}) from Table 5.7.5. These data are quarterly. We take the data for the fourth quarter of each year to get the end-of-period stock corresponding to the end-of-period stocks for equipment and structures. Corporate profit taxes (CT) are measured by taxes on corporate income in Table 6.18.

The following variables come from the BEA's "Fixed Assets" tables. The variable δk, called consumption of fixed capital (CFC), is measured by the series called "current cost depreciation of private fixed assets" in Table 3.4ES in the September 2002 version of these tables. Investment in equipment and structures is taken from Table 3.7ES in the same version. The variable k_{ES}, which measures the fixed capital, the sum of equipment and structures, is taken from the BEA data on fixed assets from Table 3.1ES "Current Cost Net Stock of Private Fixed Assets by Industry." These data are end-of-year stocks. We use the number for year t at the beginning-of-year stock for year $t+1$.

The variable k_{Land}, which measures the stock of land, is taken from the U.S. Labor Department's Bureau of Labor Statistics Web site, which includes data on its multifactor productivity program. (We use the zipped file k2dscdod.txt, which has a table on the stock of land in manufacturing in 1996 dollars, and the price deflator used to convert the stock of land to current dollars. This file is found by starting at www.bls.gov/web/prod3.supp.toc.htm and following the link to "Capital Services by Asset Type for Major Sectors.") We thank a referee for pointing us to these data on land.

Appendix B

The Appropriate Measure of the Real Interest Rate i? [Not for Publication]

McGrattan and Prescott (forthcoming) argue that in an economy in which corporate investments are financed out of retained earnings, the appropriate measure of $1+i$ in (A3) is the consumer's marginal rate of substitution, which equals the return that households can obtain on investments after personal income taxes. We demonstrate this result formally in a simple economy. In this economy, a representative household faces a constant personal income tax rate τ_p that applies equally to interest income, dividends, and capital gains. A representative firm faces a constant corporate tax rate τ_c. To keep the notation simple, we assume that this firm is all equity financed.

The household chooses consumption c_t, labor l_t, and shareholdings s_t to maximize

$$\max \sum_{t=0}^{\infty} \beta^t U(c_t, l_t)$$

subject to a sequence of budget constraints

$$c_t + q_t s_t = w_t l_t + (1-\tau_p) d_t s_{t-1} + q_t s_{t-1} - \tau_p (q_t - q_{t-1}) s_{t-1}, \tag{A5}$$

where q_t is the price of a share of the firm's dividends from period $t+1$ onward, and w_t is the real wage. The first-order conditions for consumption and shareholdings s_t are that

$$\beta^t U_{ct} = \lambda_t \tag{A6}$$

$$\lambda_t q_t = \lambda_{t+1} \left[(1-\tau_p) d_{t+1} + q_{t+1} - \tau_p (q_{t+1} - q_t) \right], \tag{A7}$$

where λ_t is the multiplier on the budget constraint. We convert the sequence of budget constraints in (A5) to a period 0 budget constraint by multiplying the constraints in (A5) by λ_t and summing to obtain

$$\sum_{t=0}^{\infty} \lambda_t (c_t - w_t l_t) = \sum_{t=0}^{\infty} \lambda_t \left[(1-\tau_p) d_t s_0 \right], \tag{A8}$$

where $s_0 = 1$ in equilibrium. Note that the intertemporal price between periods t and $t+1$ in this budget constraint is

$$\frac{U_{ct}}{\beta U_{ct+1}} = \frac{\lambda_t}{\lambda_{t+1}} = \frac{(1-\tau_p) d_{t+1} + q_{t+1} - \tau_p (q_{t+1} - q_t)}{q_t} \tag{A9}$$

and, hence, is equal to the rate of return on equity, after personal income taxes.

The representative firm holds the physical capital stock k_t, pays corporate taxes τ_c, and pays dividends d_t, where

$$d_t = F(k_t, l_t) - w_t l_t - x_t - \tau_c \left[F(k_t, l_t) - w_t l_t - \delta k_t \right]. \tag{A10}$$

Here F is the production function, x_t is investment (which is financed out of retained earnings), and δ is the depreciation rate. The capital accumulation law is $k_{t+1} = x_t + (1-\delta) k_t$.

Consider the consumer, acting as owner of the firm, choosing the objective function that the firm should maximize. It is clear from (A8) that the consumer would like the representative firm to maximize the right side of the consumer budget constraint. Hence, the firm's problem can be written as maximizing

$$(1-\tau_p)\sum_{t=0}^{\infty}\lambda_t d_t$$

subject to (A10) and the capital accumulation law. The first-order condition for capital k_{t+1} can be written as

$$\frac{\lambda_t}{\lambda_{t+1}} = 1 + (1-\tau_c)(r_{t+1}-\delta), \tag{A11}$$

where $r_{t+1} = F_{kt+1}$ is the marginal product of capital. Note that (A9) and (A11) together imply (A3), where

$$1 + i_{t,t+1} \equiv \frac{\lambda_t}{\lambda_{t+1}}.$$

TABLE 1

ACCOUNTING FOR OUTPUT IN THE U.S. MANUFACTURING SECTOR

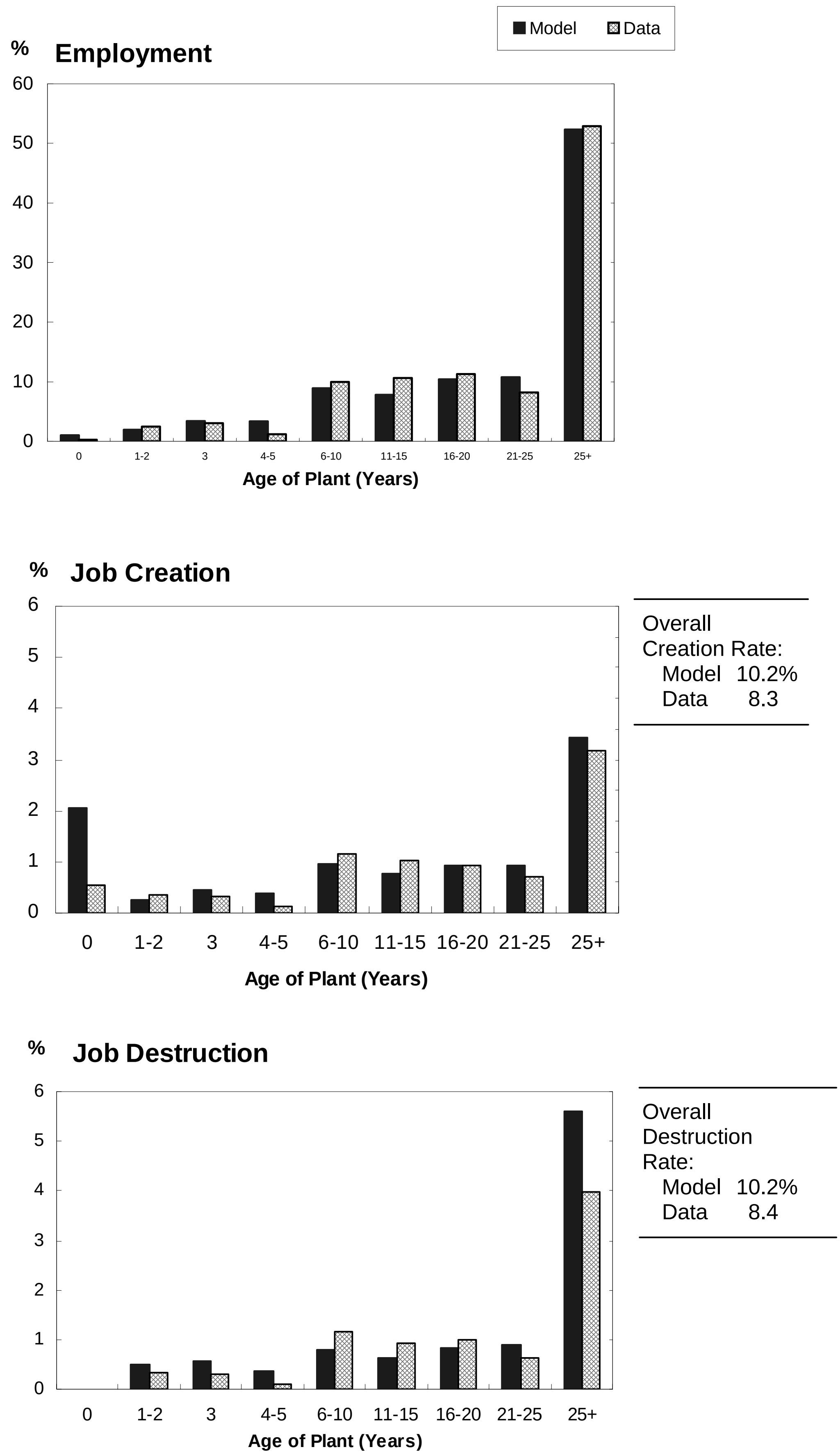
	Data (on U.S. Manufacturing)[a]	Model		
		$\nu = .80$	$\nu = .85$	$\nu = .90$
Shares of output				
Labor	72.2%	75.7%	76.8%	77.9%
Workers	—	60.1	65.1	70.1
Managers	—	15.6	11.7	7.8
Physical capital	19.9	19.9	19.9	19.9
Intangible capital	8.0	—	—	—
Organization capital	—	4.4	3.3	2.2
Other payments				
Net payments to physical capital[b]	7.3	8.9	8.9	8.9

[a]U.S. manufacturing data are described in Appendix A.

[b]Net payments to physical capital are measured net of new investment, that is, as $rk - x$.

Fig. 1—Employment statistics by manufacturing plant age in the model and in the 1988 U.S. data

(% of total employment)



Source of data: Davis, Haltiwanger, and Schuh 1996

Fig. 2—Mean and standard deviation of shocks to plant size by age of plant

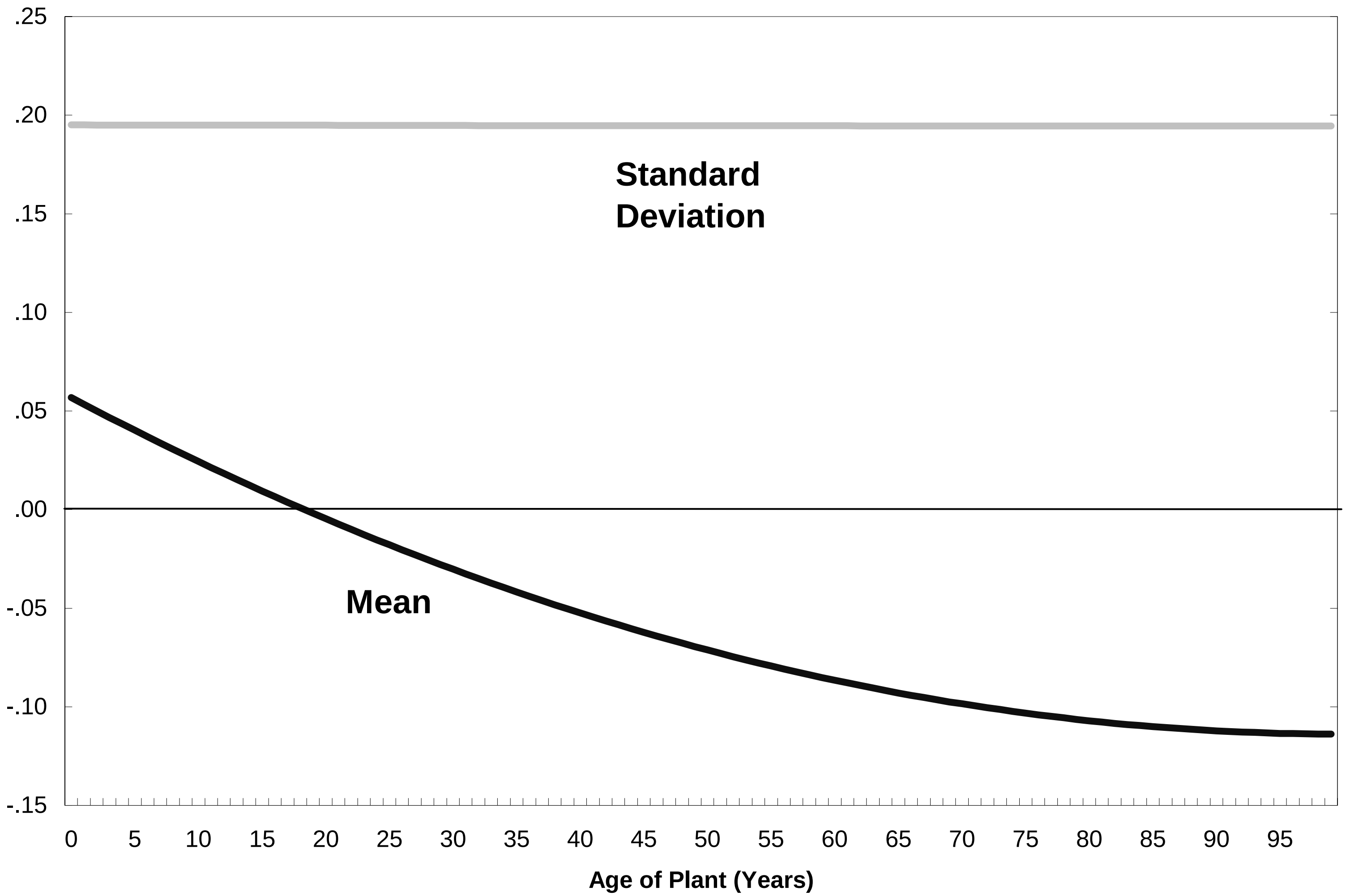
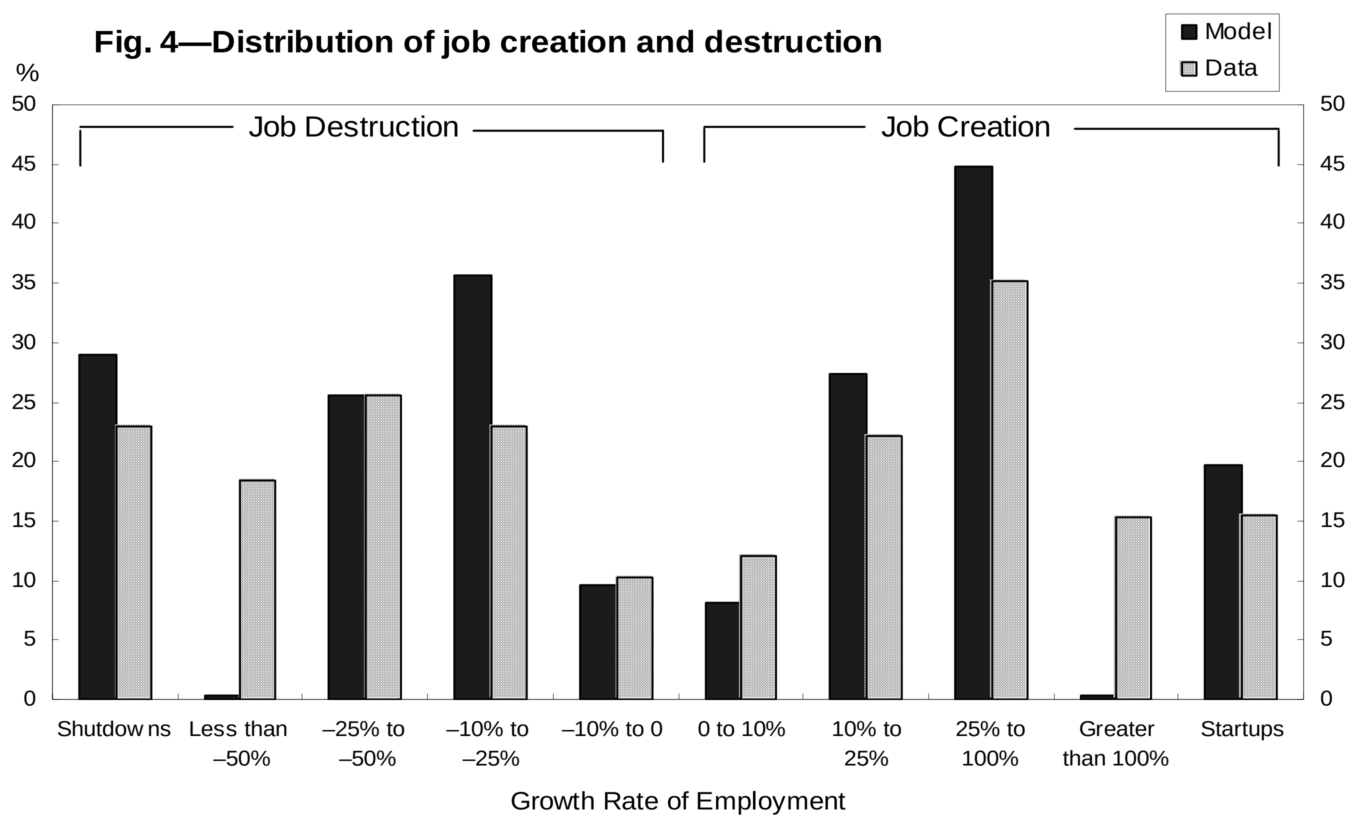


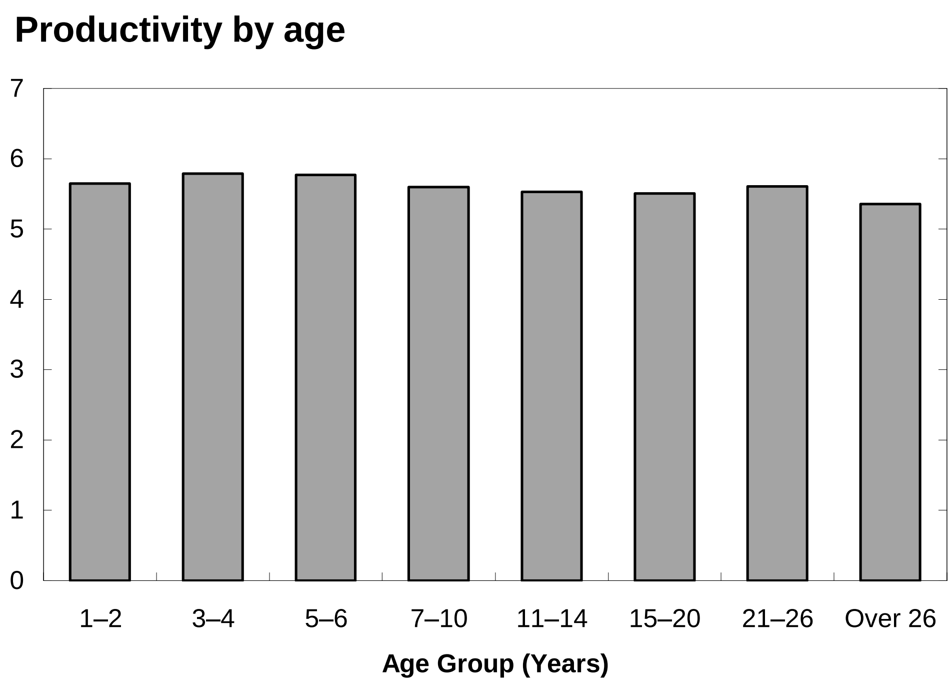
Fig. 3—Job destruction in failing plants by age of plant

Fig. 4—Distribution of job creation and destruction



Source of data: Davis, Haltiwanger, and Shuh 1996

Fig. 5—Average productivity of plants by age in U.S. data for 1972–86



Source: Bartelsman and Dhrymes 1998