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ABSTRACT

In the manufacturing sector of the U.S. economy, nearly 9% of output is not accounted for as payments to either physical capital or labor. The value of this output is a little larger than the value of the stock of physical capital. We build a model to measure how much of this output can be attributed to payments to organization capital-organization-specific knowledge that is built up with experience. We find that roughly 4% of output can be accounted for as payments to organization capital and that this capital has roughly two-thirds the value of the stock of physical capital.

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In the U.S. national income and product accounts (NIPA), output is accounted for as payments to labor and payments to owners of firms. In the standard growth model, output is accounted for as payments to labor and to physical capital. Using this growth model to analyze NIPA data on the U.S. manufacturing sector during 1959–99, we find that nearly 9% of the output of this sector is not accounted for by payments to either of these factors. We interpret this unaccounted-for output as payments to various forms of unmeasured capital or monopoly rents. The discounted present value of this unaccounted-for output is about 120% of the value of the stock of physical capital. In this paper, we build a model of one type of unmeasured capital in organizations and measure the portion of unaccounted-for output that can be accounted for as payments to this form of capital.

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 that is distinct from the concepts of physical or human capital in the standard growth model. Following Prescott and Visscher (1980), we call this knowledge *organization capital*.

We find that 4% of output in the U.S. manufacturing sector can be accounted for as payments to organization capital. Thus, a little less than half of the nearly 9% unaccounted-for output in manufacturing can be accounted for as payments to organization capital. In the model, the discounted present value of payments to organization capital is 66%, or about two-thirds, of the value of physical capital.

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, specific productivity grows stochastically at a rate that depends on its age. We interpret this growth of a plant's specific productivity as arising from a stochastic learning process.

To quantify the learning process 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, 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.

In terms of the literature, two broad themes have emerged since Marshall's (1930) work. One theme 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 this firm-specific human capital. Another theme in the literature is that organization capital is a firm-specific capital good jointly produced with output and embodied in the organization itself. Arrow (1962), 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 second theme and regard organization capital as embodied in the organization and as being jointly produced with measured output.

We model specific productivity as an exogenous stochastic process in a manner similar to that of Hopenhayn and Rogerson (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 economy considered here is a steady state version of the one in our earlier work, Atkeson and Kehoe (2001), which we used to study the transition of the U.S. economy following the Second Industrial Revolution. Here we use this model to measure the value of organization capital in the U.S. economy.

1. The value of unaccounted-for output in U.S. manufacturing

Here we analyze data on the U.S. manufacturing sector during 1959–99. We ask what fraction of output cannot be accounted for by payments to labor and physical capital. This unaccounted-for output must be payments to owners of firms as corporate profits, proprietor's income, or net interest that cannot be accounted for as payments to physical capital.

We find that roughly 9% of U.S. manufacturing output is unaccounted for.[1] The value of this unaccounted-for output is about 120% of the value of the physical capital stock in this sector. We think of this unaccounted-for output as payments to various forms of unmeasured capital, including monopoly rents.

We arrive at this conclusion by measuring payments to labor and to physical capital during 1959–99 as a share of output. The payments to labor can be obtained from the NIPA (U.S. Commerce, various dates).[2] On average during the 1959–99 period, these payments are 72.9% of the gross output of this sector. To measure the payments to physical capital, we use a growth model with equipment and structures. We find that, on average, the payments to physical capital are 18.4% of the output of this sector. Thus, 8.7% of the output of this sector (or roughly 9%) is not accounted for by payments to either labor or physical capital.

We interpret this unaccounted-for output as a net flow of payments to the owners of the manufacturing sector. Thus, to the extent that these are payments to unmeasured capital, these payments are net of the costs of investing in that capital. One way to gain some perspective on the magnitude of this flow is to compare it to the flow of returns that the owners of physical capital receive net of the cost of investing in new capital. Since investment in physical capital has averaged 11.0% of output in manufacturing, these returns are 7.4% ($= 18.4 - 11.0$) of the output of this sector. Since the value of either type of capital is the present value of their flows, we conclude that the value of the claim to unaccounted-for output in this sector is 119% ($\cong 8.7/7.4$) of the value of the stock of physical capital in this sector.

We measure the payments to physical capital as follows. In a growth model with equipment and structures, the payments to physical capital are given by $r^E k^E + r^S k^S$, where

r^E and r^S are the rental rates and k^E and k^S are the stocks of the two types of capital. In the U.S. data, the value of each stock of capital is recorded, but the rental rates are not. Thus, to measure the portion of output that can be accounted for as payments to physical capital, we must measure these rental rates indirectly.

To do so, let i denote the rate of return on financial assets, namely, the return to the portfolio of financial claims on firms. In the model, this return is equal to the return from buying one unit of capital of either type in period t after corporate income taxes and changes in the relative price of that type of capital are taken into account. Thus, equating these returns gives

$$1 + i_t = [(1 - \tau_c)r^j_{t+1} + \tau_c p^j_{t+1}\delta^j + (1 - \delta^j)p^j_{t+1}]/p^j_t, \tag{1}$$

where r^j, p^j, and δ^j are the rental rate, price, and depreciation rate on capital of type $j = E, S$ and τ_c is the corporate income tax rate. As described below, we measure $i = 5.7\%$, $\delta^E = 11.1\%$, $\delta^S = 3.0\%$, $p^E_{t+1}/p^E_t = 98.3\%$, $p^S_{t+1}/p^S_t = 101\%$, and $\tau_c = 30.5\%$. From (1), these figures imply rental rates of $r^E = 22.0\%$ and $r^S = 9.9\%$, which together with measured physical capital/output ratios of $k^E/y = 62.9\%$ and $k^S/y = 45.5\%$ imply capital shares of $r^E k^E/y = 13.9\%$ and $r^S k^S/y = 4.5\%$, for a total capital share of 18.4%.

To measure the return on financial assets i, we compute the average return to the portfolio of financial claims on the nonfinancial corporate business sector. This return is a weighted average of returns on equity, long-term corporate debt, and short-term debt, where the weights are determined by the weights of these categories in the total value of claims on that sector. We obtain values for real asset returns from Ibbotson Associates (2000). Since real asset returns are volatile, we use the longest consistent time series available to compute their average returns and, hence, take averages over the period 1926–99. These averages are 7.94% for equity (the Standard & Poor's 500-stock price index), 2.46% for long-term corporate bonds, and .7% for short-term debt (30-day U.S. Treasury bills). We obtain the weights for the categories by taking average shares over the period 1959–99 from the Federal Reserve System's U.S. flow of funds accounts (FR Board, various dates, Table L102). For weights for equity returns, long-term bond returns, and short-term debt returns, we use the average of the weights in the total market value of the three items: equities (line 41), 63%; securities and mortgages (line 42), 22%; and loans and short-term paper (line 43), 15%.

We measure the depreciation rates as the ratio of the depreciation to the current cost of capital reported by the U.S. Bureau of Economic Analysis (Herman 2000). We measure the prices of equipment and structures as the implicit price deflators (from Table 7.1 of the NIPA). We measure the corporate tax rates τ_c as the average of the ratio of corporate profits tax payments for the nonfinancial corporate business sector to the sum of corporate profits and net interest for that sector (using Table 1.16 of the NIPA).

Our estimate for the share of output unaccounted for clearly depends on the return on financial assets i. We measure that return as $i = 5.7\%$. In Figure 1, we plot the share of output paid to physical capital and the share of output unaccounted for against the return on financial assets i. For example, if i were 4%, then the share of output paid to physical capital would be 15.7% and the share of output unaccounted for would be 11.4%, while if i were 8.0%, the physical capital share would be 21.9% and the share of unaccounted-for output would be 5.1%. The share of unaccounted-for output would be zero only if the interest rate were 11.25%. In Figure 2, we plot the corresponding ratio of the value of unaccounted-for output relative to the value of physical capital against the return on financial assets. When

i is 4%, this ratio is 247%; when i is 8%, the ratio is 47%; and when i is 11.25%, it is zero.

The share of output unaccounted for is much higher in the manufacturing sector than in the nonfinancial corporate sector as a whole. For the larger sector, the share of payments to labor is 72.5% while, based on the same methodology as above with $i = 5.7\%$, the share of payments to physical capital is 24.8%. This leaves only 2.7% of output not accounted for instead of 8.7%. The major reason for this difference between the two sectors is that the capital/output ratio is much higher in the nonfinancial corporate sector than it is in manufacturing (1.64 vs. 1.08). In the nonfinancial corporate sector, the investment/output ratio has averaged 15.2%; thus, the value of a claim to unaccounted-for output relative to the value of the stock of physical capital is only 28%. (Larkins 2000 performs a similar calculation of factor payments for all domestic nonfinancial corporations and arrives at similar numbers.)

2. A model of organization capital

In this section, we develop our quantitative model of organization capital. In the model, time is discrete and is denoted by periods $t = 0, 1, \ldots,$. The economy has two types of agents: workers and managers. There exist a continuum of size 1 of workers and a continuum of size 1 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 in period 0. Workers have preferences over consumption given by $\sum_{t=0}^{\infty} \beta^t \log(c_{wt})$, where β is the discount factor. Given sequences of wages and intertemporal prices $\{w_t, p_t\}_{t=0}^{\infty}$, initial capital holdings k_0, and an initial value a_0 of the plants that exist in period 0, workers choose sequences of consumption $\{c_{wt}\}_{t=0}^{\infty}$ to maximize utility subject to the budget constraint

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

Managers are endowed with one unit of managerial time in each period. Managers have preferences over consumption given by $\sum_{t=0}^{\infty} \beta^t \log(c_{mt})$. 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 utility subject to the budget constraint $\sum_{t=0}^{\infty} p_t c_{mt} \leq \sum_{t=0}^{\infty} p_t w_{mt}$. Notice that we have given all the initial assets to the workers. Since worker and manager utilities are identical and homothetic, aggregate variables do not depend on the initial allocation of assets.

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 one unit of a manager's time, physical capital, and (workers') labor as variable inputs. If a plant with specific productivity A operates with one manager, capital k, and labor l, the plant produces output

$$y = zA^{1-\nu} F(k, l)^{\nu}, \tag{3}$$

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 the plant's manager. The parameter ν may be interpreted more broadly as determining the degree of diminishing returns at the plant level. We refer to the pair (A, s) as the plant's *organization-specific capital,* or simply its *organization capital.* This pair summarizes the built-up expertise that distinguishes one organization 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 (3). 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. This frontier technology evolves 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:

$$\max_{k,l} z_t A^{1-\nu} F(k,l)^{\nu} - r_t k - w_t l - w_{mt}. \tag{4}$$

Define

$$d_t(A) = z_t A^{1-\nu} F\left(k_t(A), l_t(A)\right)^{\nu} - r_t k_t(A) - w_t l_t(A), \tag{5}$$

where $k_t(A)$ and $l_t(A)$ are the solutions to this problem. The *dividend* to 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

$$V_t(A, s) = \max\left[0, V_t^c(A, s)\right], \tag{6}$$

where

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

and 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 term $V_t^c(A, s)$, the expected discounted value of operating a plant of type (A, s), 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 $V_t^c(A, s)$ from operating it are nonnegative.

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

$$V_t^0 = -\, w_{mt} + \frac{p_{t+1}}{p_t} V_{t+1}(\tau_{t+1}, 0). \tag{7}$$

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

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 sign of the function $V_t^c(A, s)$ according to

$$\lambda_t(A, s) = \int_0^A 1_{V^c}(a, s)\mu_t(da, s),$$

where $1_{V^c}(a, s) = 1$ if $V_t^c(a, s) \geq 0$ and 0 otherwise. 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:

$$\mu_{t+1}(A', s+1) = \int_A \pi_{s+1}(A'/A)\lambda_t(dA, s) \tag{8}$$

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 $c_{wt} + c_{mt} + k_{t+1} = y_t + (1-\delta)k_t$, where y_t is defined by $y_t = z_t \sum_s \int_A A^{1-\nu} F\big(k_t(A), l_t(A)\big)^\nu \lambda_t(dA, s)$. The resource constraint for managers is

$$\phi_t + \sum_s \int_A \lambda_t(dA, s) = 1. \tag{9}$$

Managers are hired to prepare blueprints 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 that $V_t^0 \leq 0$. We summarize this condition as $V_t^0 \phi_t = 0$. 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 frontier 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; 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 for plants $\left\{\lambda_t, \mu_{t+1}, \phi_t\right\}$; value functions and operating decisions $\{d_t, V_{t,} V_t^c, V_t^0\}$; and prices $\{w_t, r_t, w_{mt}, p_t, \}$, all of which satisfy the above conditions.

3. Variable profits, size, and value of plants

Now we link the variable profits $d_t(A)$ of a plant to the size of that plant as measured by its employment. We will calibrate the model to match U.S. data on the pattern of plant employment growth with age. We use this link to argue that our model will thus also match the evolution of variable profits of plants as they age. We then compute the value of these plants by computing the present discounted value of their variable profits. Finally, we show that if we choose parameters to hold constant the model's implications for the size of plants, then the value of plants is invariant to the decomposition of technical change into the part that is embodied and the part that is economy-wide.

Consider 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 in period t is static. For a given distribution λ_t of organization capital, it is convenient to define

$$n_t(A) = \left(\frac{A}{\bar{A}_t}\right) \tag{10}$$

as the *size* of a plant of type (A, s) in period t, where

$$\bar{A}_t = \sum_s \int_A A\lambda_t(dA, s) \tag{11}$$

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) is

$$d_t(A) = (1 - \nu)y_t(A) = (1 - \nu)n_t(A)y_t.$$

Variable profits $d_t(A)$ minus managerial wages w_{mt} are the profits earned on organization capital. The value function $V_t(A, s)$ is the discounted value of these profits from t

on.

The value of a plant of type (A, s) at the beginning of period $t+1$ measured in units of period t consumption goods is composed of two parts: the value of its physical capital and the value of its organization capital. The value of physical capital in this plant is $k_{t+1}(A)$. Likewise, the value of organization capital in this plant is $p_{t+1}V_{t+1}(A, s)/p_t$. Hence, the value of both physical and organization capital in this plant is

$$q_t(A, s) = k_{t+1}(A) + \frac{p_{t+1}}{p_t} V_{t+1}(A, s).$$

Hence,

$$\sum_s \int_A q_t(A, s)\mu_{t+1}(dA, s) = k_{t+1} + \frac{p_{t+1}}{p_t} \sum_s \int_A V_{t+1}(A, s)\mu_{t+1}(dA, s), \tag{13}$$

where we have used the market-clearing condition $\sum_s \int_A k_{t+1}(A)\mu_{t+1}(dA, s) = k_{t+1}$. Clearly, the first term on the right side of (13) is the value of physical capital in all plants while the second term is the value of organization capital in all plants.

Now consider our model's implications for the size and value of plants on a steady-state growth path. To ensure that our model has a balanced growth path, we assume that $F(k, l) = k^{\theta} l^{1-\theta}$.[3] 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 a 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 $1+g = [(1+g_z)(1+g_\tau)^{1-\nu}]^{1/(1-\nu\theta)}$; 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 $V_{t+1}(A, s) = (1+g)V_t\big((A/(1+g_\tau), s\big)$, $d_{t+1}(A, s) = (1+g)d_t\big(A/(1+g_\tau), s\big)$, and $V^c_{t+1}(A, s) = (1+g)V^c_t\big(A/(1+g_\tau), s\big)$ for all t, A, s.

Note that, by definition, the size-age distribution of plants is constant along the steady-state growth path. Now we show that data on the size-age distribution of plants do not pin down the span of control parameter ν. Define functions $W(n, s)$, $W^c(n, s)$, and $W^0(n, s)$ such that for $n = A/\bar{A}_0$, $W(n, s) = V_0(n\bar{A}_0, s)$, $W^c(n, s) = V^c_0(n\bar{A}_0, s)$, and $W^0(n, s) = V^0_0(n\bar{A}_0, s)$. Let $\{\rho_s\}$ be the cumulative distribution functions of $\eta = \epsilon/(1+g_\tau)$ induced by $\{\pi_s\}$. We refer to $\{\rho_s\}$ as the *steady-state distributions of shocks to plant size.* Consider another Bellman equation

$$W(n, s) = \max\left[0, W^c(n, s)\right], \tag{14}$$

where

$$W^c(n, s) = d_0(\bar{A}_0 n) - w_{m0} + \beta \int_\eta W(n\eta, s+1)\rho_{s+1}(d\eta)$$

$$w_{m0} = \beta W(\tau_0/\bar{A}_0, 0).$$

By definition of the value functions V, V^c, V^0 along the steady-state path, W satisfies this equation. The terms in this second Bellman equation (14) have the same interpretation as those in the first (6), as descriptions of the returns to operating or closing a plant of size n and age s. The function $W^c(n, s)$ defines a rule for operating plants: plants with $W^c(n, s) \geq 0$ operate, and those with $W^c(n, s) < 0$ do not.

Having replaced specific productivity with size as a state variable, we have the following proposition:

Proposition. Consider two economies with the same steady-state growth rate g and the same distribution of shocks to size. Let these economies have different rates of growth of economy-wide and embodied technical change that satisfy

$$(1+g_z)(1+g_\tau)^{1-\nu} = (1+g'_z)(1+g'_\tau)^{1-\nu},$$

so that the two economies have the same steady-state growth rate of output g. Let the distributions of shocks to specific productivity correspondingly differ so that $\epsilon/(1+g_\tau)$ and $\epsilon/(1+g'_\tau)$ have the same distribution. Then these two economies have the same steady-state size-age distribution of plants and the same value of organization capital.

Proof. Since the economies have the same distribution of shocks to size, the decision to operate plants of size n and age s in both economies is characterized by the solution to (14); thus, the economies have the same steady-state size-age distribution of plants. By definition, the value functions are the same; thus, so are the values of organization capital. Clearly, the rest of the equilibrium prices and quantities are the same as well. Q.E.D.

4. Calibration and measurement

Now we calibrate our model. We draw on aggregate data from the U.S. manufacturing sector to determine the growth rate of output per hour g, the discount factor β, the depreciation rate δ, the physical capital share $\nu\theta$, and the growth rate of aggregate total factor productivity which must be allocated between growth in the frontier technology and growth in the economy-wide technology. We use observations from micro data on manufacturing plants in the United States to choose the parameters affecting the shocks to size.

The macro parameters are chosen to reproduce several average statistics observed in the data on the U.S. manufacturing sector during 1959–99, obtained from the U.S. Department of Commerce's national income and product accounts (NIPA). To match the model to observations, we introduce a corporate profits tax τ_c since tax payments of this type comprise a substantial portion of the output of the corporate sector. 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

$$\frac{c_{t+1}}{\beta c_t} = \frac{1+g}{\beta} = (1-\tau_c)(\nu\theta\frac{y_{t+1}}{k_{t+1}} - \delta) + 1. \tag{15}$$

We use data from the U.S. Department of Labor (various dates) on output per hour of all persons in manufacturing to compute the trend growth rate of output from 1959 to 1999, which turns out to be $g = 2.9\%$. We choose the discount factor β so that the ratio $(1+g)/\beta$ equals the average rate of return on financial assets that we computed above to be 5.7%.

We choose the parameters of our one-sector model to equal the relevant aggregates in the manufacturing sector: the total depreciation rate on capital in manufacturing is $\delta = 7.7\%$, the total capital/output ratio is $k/y = 116\%$, the physical capital share of $\nu\theta = 18.4\%$, and the corporate profits tax rate is $\tau_c = 30.5\%$.

Consider next the growth of the Solow residual. The steady-state growth rate of output per worker, $1+g$, is related to the growth of the Solow residual by $(1+g)^{1-\nu\theta}$, which can be decomposed as $(1+g)^{1-\nu\theta} = (1+g_z)(1+g_\tau)^{1-\nu}$. Given our choices of $g = 2.9\%$ and $\nu\theta = 18.4\%$, the growth of the Solow residual is $(1+g)^{1-\nu\theta} = 1.024$. Since we calibrate our model to reproduce observations on plant size, the steady state is not affected by this decomposition of the Solow residual. For concreteness, we let all the growth come from the growth in the frontier technology.

Now consider the span of control parameter ν. 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 (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); and Bartelsman and Dhrymes (1998). Atkeson, Khan, and Ohanian (1996) review this literature and present evidence, in the context of a model like ours, that $\nu = .85$ is a reasonable value for this parameter.

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 and standard deviations of these distributions to be smoothly declining functions of s. In particular, we set $m_s = \gamma_1 + \gamma_2(\frac{S-s}{S})^2$ for $s \leq S$ and $m_s = \gamma_1$ otherwise and $\sigma_s = \gamma_3 + \gamma_4(\frac{S-s}{S})^2$ for $s \leq S$ and $\sigma_s = \gamma_3$ 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 $\{\gamma_i\}_{i=1}^4$ 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 job destruction in plants of different age groups, from the 1988 panel of the U.S. Census Bureau's Longitudinal Research Database (the LRD).[4] We choose the data from this panel because it has the most extensive breakdown of plants by age. We think of 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 3, we report for each age category these three statistics for U.S. manufacturing plants in 1988 for all plants in that category relative to the total employment in all plants.

We set the parameter $S = 100$ and choose the γ_i to minimize the sum of the squared errors between the statistics computed from the model and those in the data. The resulting model statistics are also plotted in Figure 3. For completeness, note that the implied statistics for the overall job creation and destruction rates are 8.3% and 8.4% for the data and 10.4% and 10.4% for the model. To get a feel for how these numbers fluctuate, note that in annual data during 1972–93, the standard deviation of the job creation and job destruction rates are 2.0 and 2.7. In Figure 4, 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 $S = 100$, $\gamma_1 = -.1149, \gamma_2 = .1711$, $\gamma_3 = .2018$, and $\gamma_4 = .0009$.

5. Industry evolution in the steady state

We have calibrated our model to 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 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-specific capital in the data.

Specifically, we compare our model to data on job destruction in failing plants, the distribution of growth rates of capital and labor by plants, and the distribution of labor and capital productivity in plants by size and 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.

First consider plant failure rates. In Figure 5, we show job destruction in failing plants by age group for the model and the 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. Total job destruction in plants that fail is 3.0% in the model and 2.2% in the data. In terms of the breakdown of job destruction in plants that fail by age group, the model has substantially higher failure rates for the youngest plants (aged 1–5 years) than the data show. We have seen in Figure 3 (bottom panel), however, that the model has about the right amount of job destruction in plants aged 1–5. Hence, the model has too many of the young plants dying and not enough job destruction in young plants that continue.

Next consider the distribution of plant growth rates. In Figure 6, we show the distribution of plant-level job creation and job 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 of these groups.[5] 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 and size decile as measured by the average size of employment during 1972–86, where the weights are obtained from a regression of outputs on inputs. In Figure 7, we report the Bartelsman and Dhrymes values for this measure by age groups (top panel) and by size deciles (bottom panel). Although Bartelsman and Dhrymes find substantial variations in average productivity across individual plants in their data, Figure 7 demonstrates that they find no systematic relation between the average productivity in a plant and either its age or its size.

Jensen, McGuckin, and Stiroh (2001) found 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 that across individual plants, in their sample, there is extensive variation. 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.

6. Findings

Here we report our model's measure of the share of output that is paid to 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

$$y = z\bar{A}^{1-\nu} k^{\upsilon\theta} l^{\nu(1-\theta)}. \tag{16}$$

This output is paid to four factors: physical capital, workers, managers, and organization capital. The share of output paid to physical capital is $\nu\theta$; to workers, $\nu(1-\theta)$; and to managers, w_m/y; and the rest is paid to organization capital. We have calibrated the physical capital share in the model to match that in the data, so that $\nu\theta = 18.4\%$. 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 $\nu(1-\theta) = 66.6\%$.

We use the model to compute the division of the remaining 15% of output into the share paid to managers and the share paid to 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, first with $\nu = .85$. With our calibration, 11.0% of output is paid to managers, so that the share paid to labor is 77.6%, and the share paid to organization capital is 4.0%. In comparison, the shares in the data are 72.9% for labor and 8.7% unaccounted for. Our model thus accounts for about 46% (4.0/8.7) of the unaccounted-for output in manufacturing. Since the shares in our model must sum to 1, the remainder of the unaccounted-for output, 4.7% (8.7 − 4.0), must show up in another share. Since we calibrate the model to match the physical capital share, the remainder shows up as payments to managers and is thus added to the labor share, giving a total labor share of 77.6% (72.9 + 4.7).

In terms of values, the payments to physical capital net of investment are 6.1% of output (= 18.4 − 12.3). Hence, the value of organization capital relative to physical capital in the model is 66% (4.0/6.1). In the data, recall, the value of unaccounted-for output is 119% that of physical capital.

Most of the parameters of our model are well-measured. One has greater uncertainty, however: the span of control parameter ν. We consider the sensitivity of our findings to this parameter.

Consider raising ν to .9 and adjusting θ so that the physical capital share $\nu\theta$ is unchanged at 18.4%. With this change in the span of control parameter—the results of which are also shown in Table 1—the share of output paid to organization capital falls from 4.0% to 2.7%. Again, because the factor shares sum to 1, the remainder of the unaccounted-for output is attributed to labor. The ratio of the value of organization capital relative to physical capital falls from 66% to 44%.

More generally, we can show that the payments to organization capital relative to the sum of the payments to organization capital and managers is independent of ν. To see this, note from (6) and (7) 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

$$\frac{\tilde{w}_{mt}}{1-\tilde{\nu}} = \frac{w_{mt}}{1-\nu}.$$

Since $1-\nu$ is the sum of managerial wages and payments to organization capital, the result follows.

In Table 1, we see that of the 15% share paid to organization capital and managers, organization capital gets roughly one-quarter of the share and managers get roughly three-quarters. 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 $3(1-\nu)/4$.

7. Conclusion

We have found that nearly half of the unaccounted-for output in the U.S. manufacturing sector can plausibly be attributed to organization capital and that the value of this organization capital is roughly two-thirds of the value of the physical capital stock. This organization capital is produced as part of the turbulent and time-consuming process of building up a stock of organization-specific knowledge in plants. Our measurement of the value of this capital—4% of manufacturing output—is based on micro data on the birth, growth, and death of plants.

Still, despite our measurement of organization capital, 4.7% of output in the manufacturing sector remains unaccounted for. Presumably, this remainder can be attributed to other forms of unmeasured capital and monopoly rents.

Note that for broader measures of output, like that in the nonfinancial corporate sector, a much smaller fraction of output is unaccounted for. This is consistent with the idea that knowledge built up over time in specific organizations—organization capital—is particularly important for the manufacturing sector.

Notes

[1]In measuring output, we subtract indirect business taxes from the NIPA measure of gross output.

[2]We divide the 1.4% of manufacturing output that is accounted for as proprietors' income between payments to labor and payments to owners of firms in proportion to the division of output less proprietors' income between labor and the owners of firms.

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

[4]Here and throughout the paper, our microeconomic data are taken from the U.S. Census Bureau's 1998 Longitudinal Research Database (LRD) on U.S. manufacturing plants. These data are broken down by crude age categories. In Figure 7, 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/.

[5]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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Table 1
Accounting for Output in the U.S. Manufacturing Sector

	U.S. Manufacturing	Model ν = .85	 ν = .9
Shares of Output			
Labor	72.9%	77.6%	78.9%
Workers	—	66.6	71.6
Managers	—	11.0	7.3
Physical Capital	18.4	18.4	18.4
Unaccounted for	8.7	—	—
Organization capital	—	4.0	2.7
Other Ratios: Values of			
Unaccounted for output/ Physical capital	119	—	—
Org. capital/Physical capital	—	66	44
Investment/Output	11.0	12.3	12.3

U.S. manufacturing data described in Section 1.

Figure 1
Share of Output Paid to Physical Capital and to Output Unaccounted For vs. Return on Financial Assets

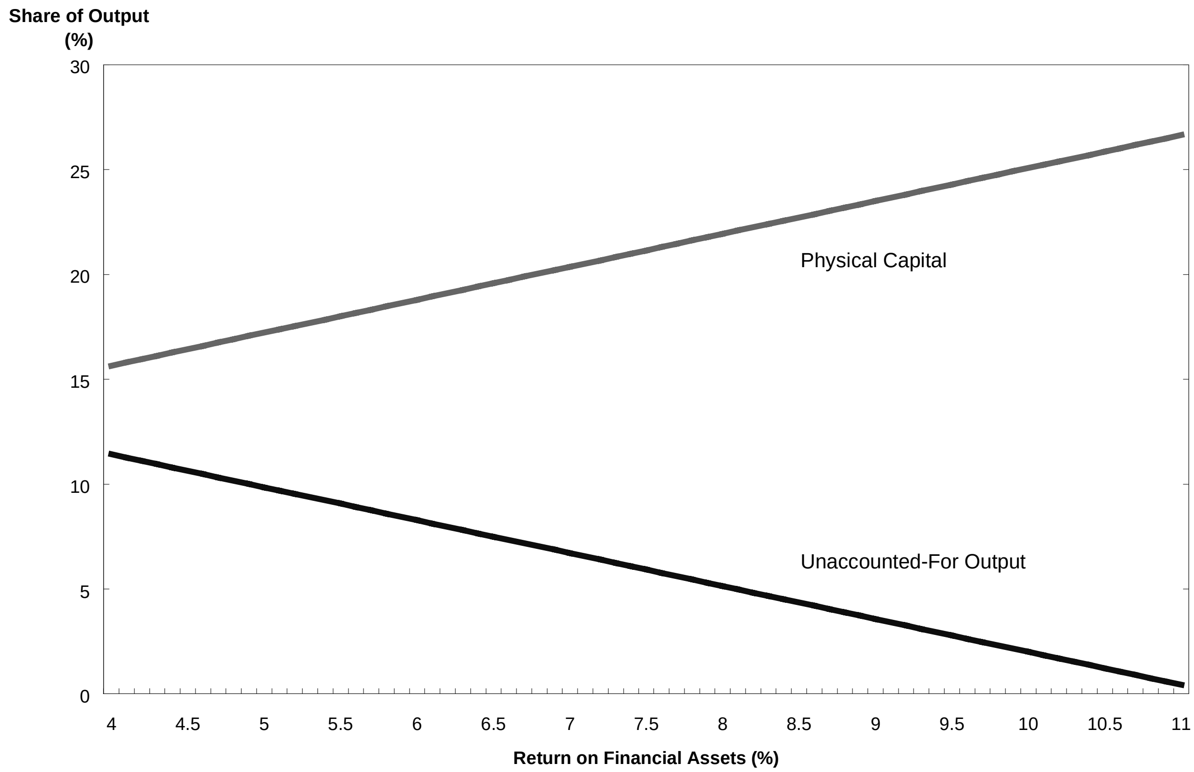


Figure 2
Unaccounted-For Output as a Percentage of Physical Capital vs. Return on Financial Assets

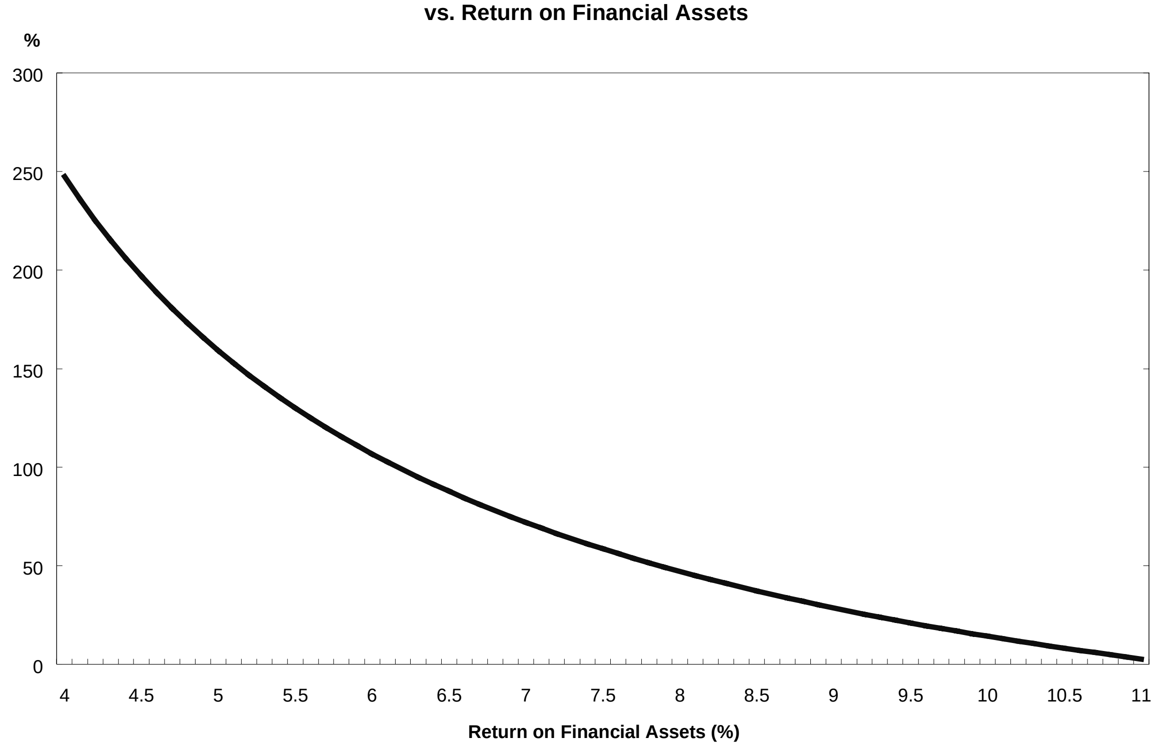


Figure 3 Employment Statistics by Manufacturing Plant Age in the Model and in the 1988 U.S. Data (% of Total Employment)

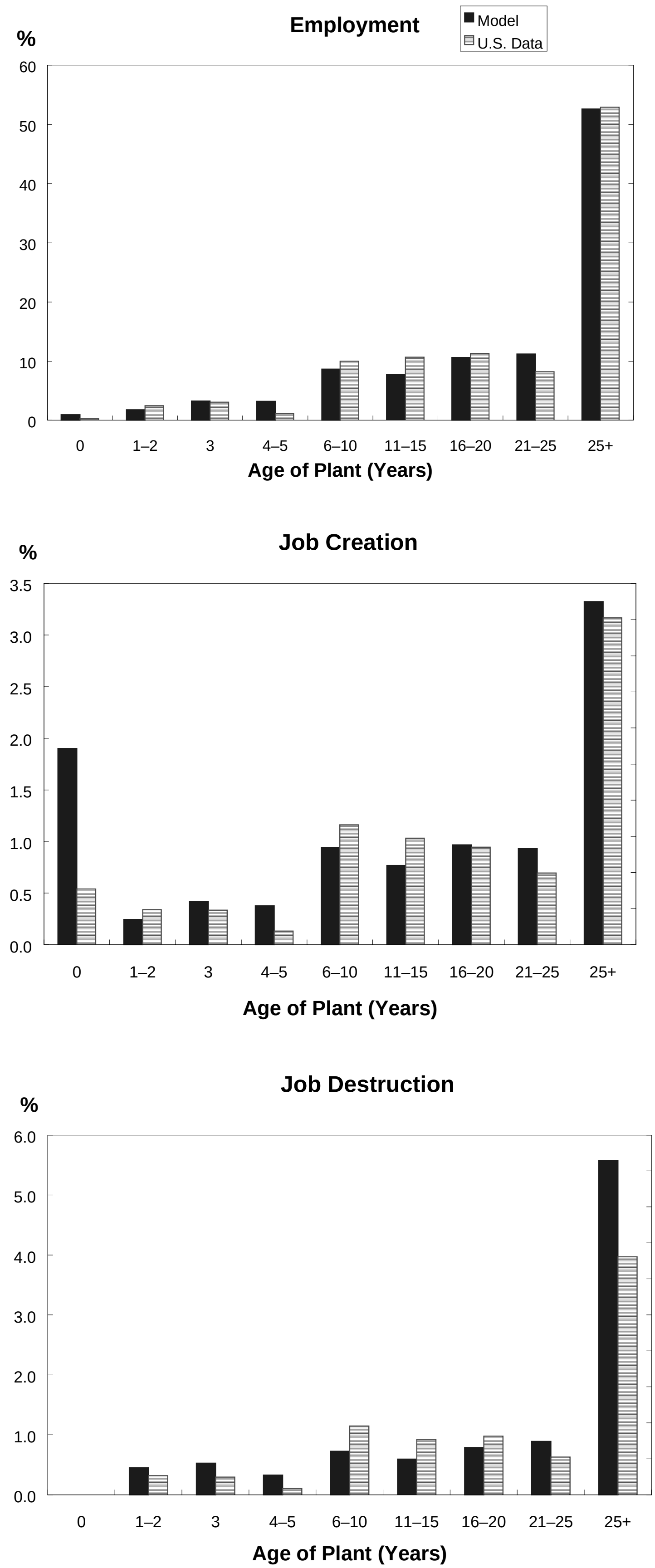


Figure 4
Mean and Standard Deviation
of Shocks to Plant Size by Age of Plant

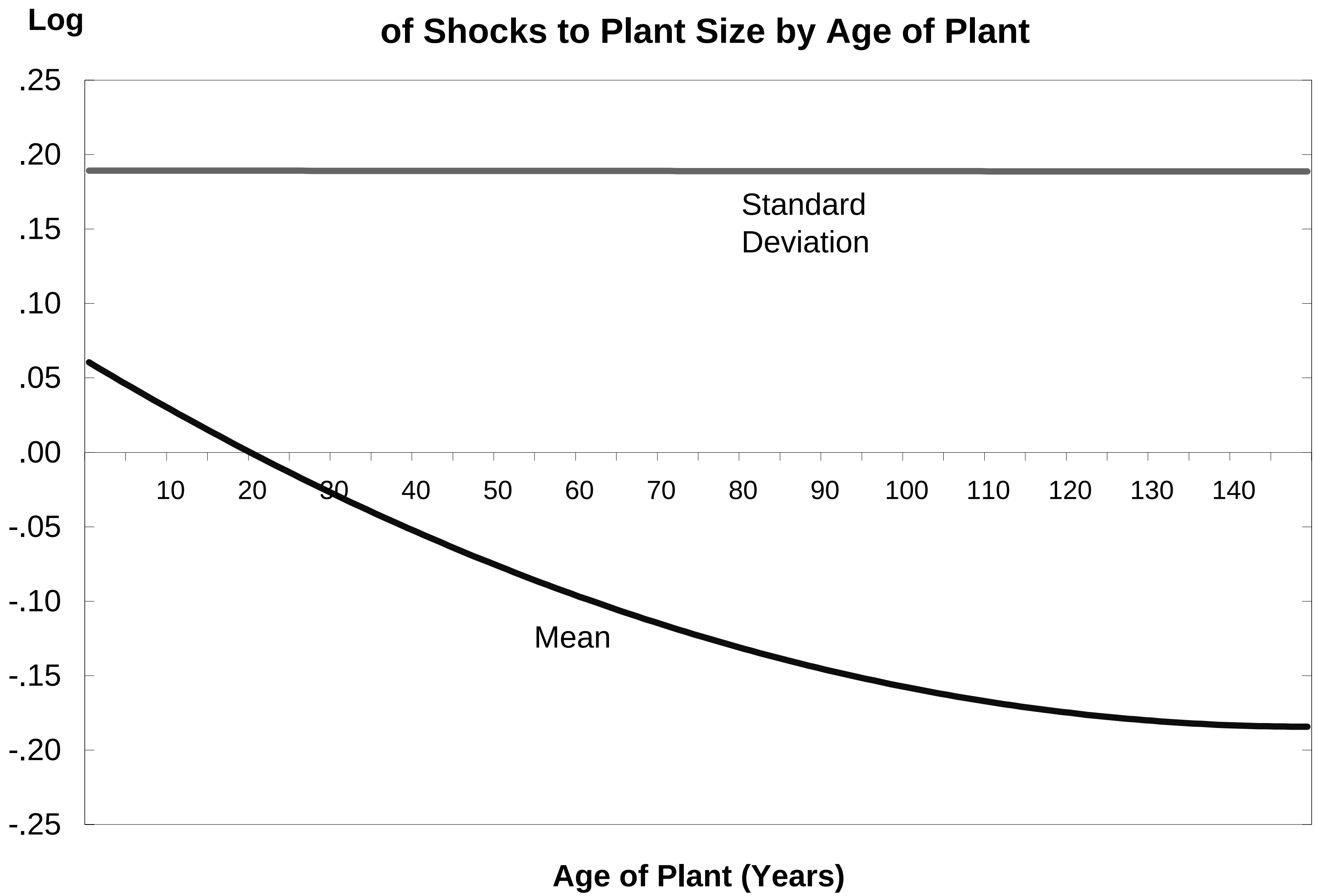


Figure 5
Job Destruction in Failing Plants by Age of Plant

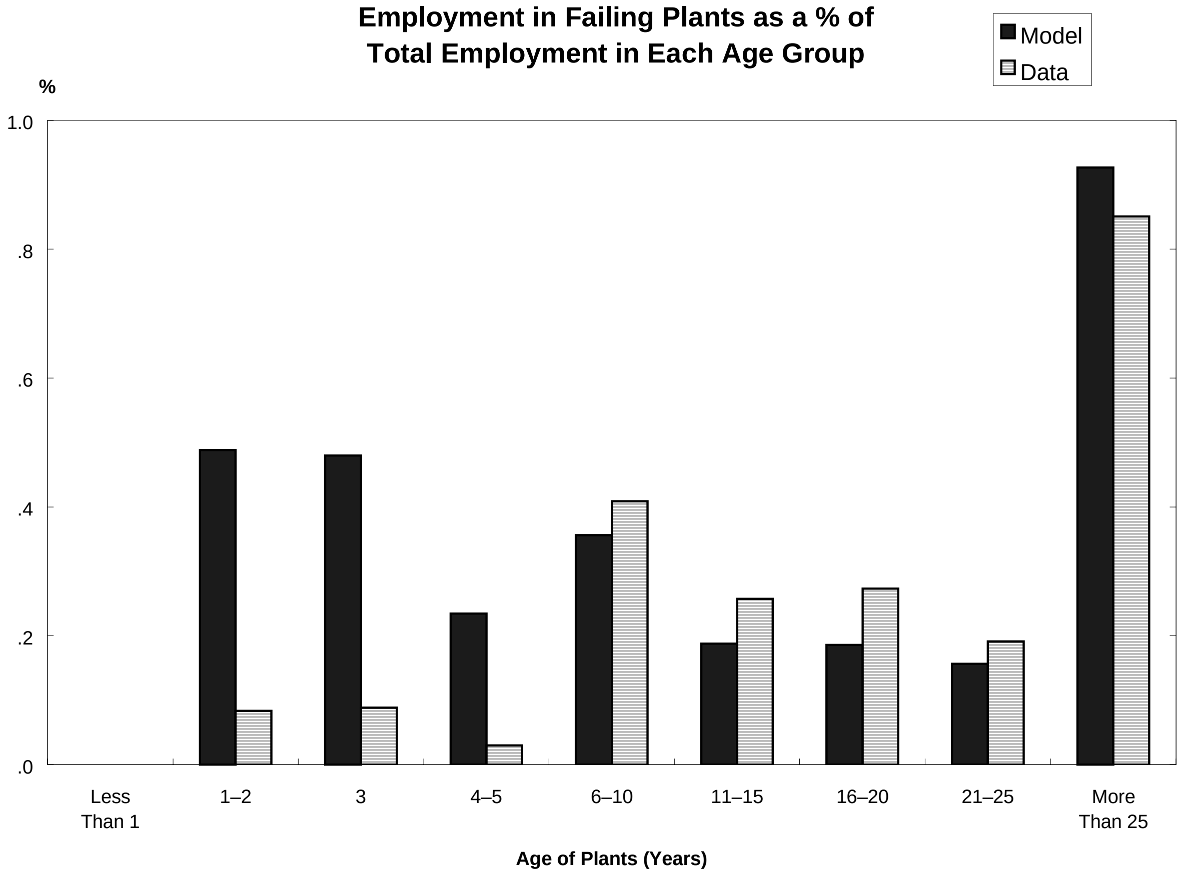


Figure 6
Distribution of Job Creation and Destruction

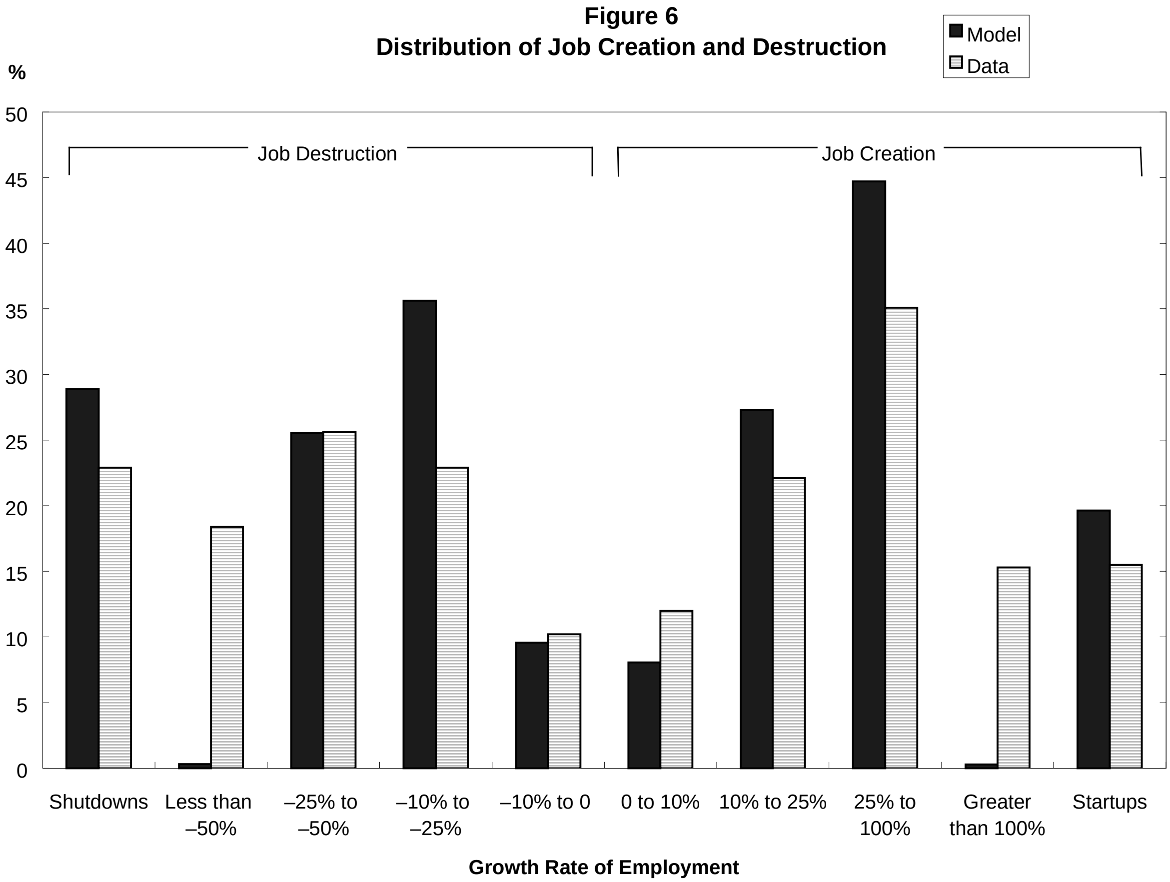
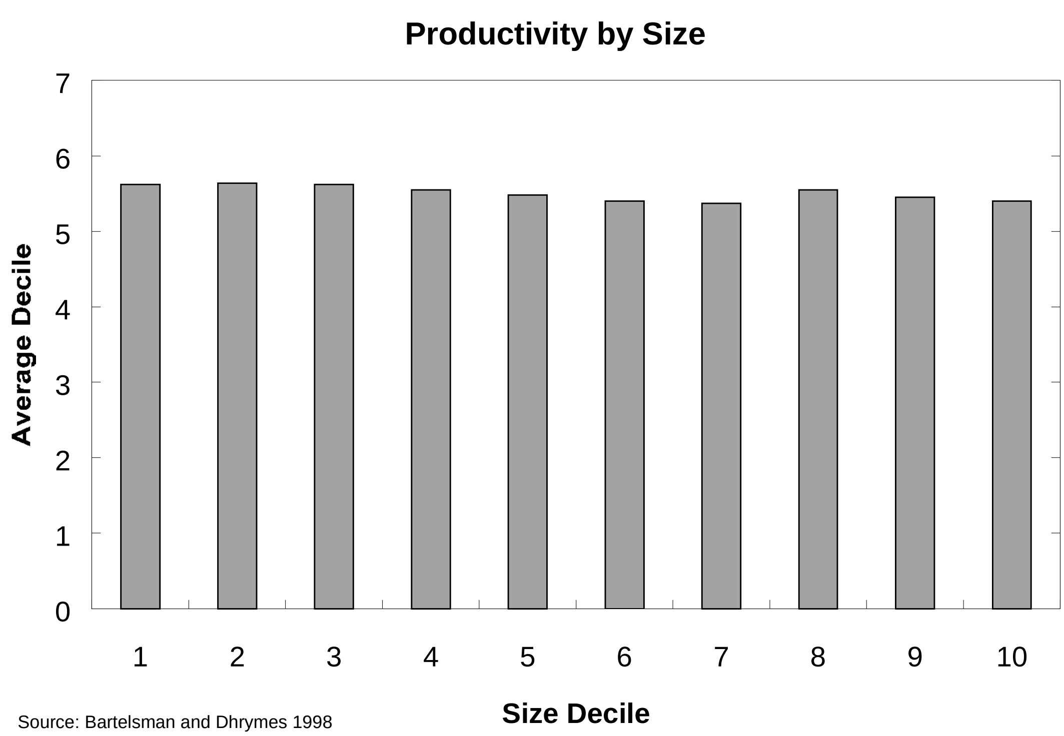


Figure 7

Average Productivity Plants by Age and Size in U.S. Data for 1972–86

Source: Bartelsman and Dhrymes 1998



Source: Bartelsman and Dhrymes 1998