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The size distribution of plants and economic development

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THE SIZE DISTRIBUTION OF PLANTS AND ECONOMIC DEVELOPMENT

by

Dhritiman Bhattacharya

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Economics
in the Graduate College of
The University of Iowa

July 2010

Thesis Supervisor: Associate Professor Gustavo J. Ventura

ABSTRACT

The plant size distribution differs systematically across developed and developing countries. For example, in developing countries, less than one fifth of 1% of plants are large (employ 100 or more employees) and account for about one fifth of total employment. In sharp contrast, in developed countries, more than 1.6% of plants are large and account for more than two fifth of total employment. In this dissertation, I develop a model of plant size to account for the differences in the plant size distribution observed in the data.

In the first chapter, I explore the link between plant size distribution and economic development. I also discuss the main features of the plant size distribution data. The purpose of this data set is to provide evidence of systematic differences in plant size distribution across developed and developing countries.

In the second chapter, I present a dynamic employment choice model in a life cycle setting. Then I calibrate the benchmark model to match some key features of the U.S. plant size distribution. I find that my model can capture the critical features of U.S. plant size distribution including the upper tail which accounts for the bulk of the employment and output in the U.S. economy.

In the third chapter, I explore how exogenous differences in aggregate barriers to investment and technology across countries affect the plant size distribution. Results indicate that exogenous differences in aggregate barriers to investment and technology across countries can account for more than 50% of the variation in both the fraction of large plants and employment share in large plants across countries. For the same group of countries, exogenous differences in aggregate barriers also account for 36% of the variation in the mean size.

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Iowa City, Iowa

CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

Dhritiman Bhattacharya

has been approved by the Examining Committee
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The plant size distribution differs systematically across developed and developing countries. For example, in developing countries, less than one fifth of 1% of plants are large (employ 100 or more employees) and account for about one fifth of total employment. In sharp contrast, in developed countries, more than 1.6% of plants are large and account for more than two fifth of total employment. In this dissertation, I develop a model of plant size to account for the differences in the plant size distribution observed in the data.

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CHAPTER 1

PLANT SIZE DISTRIBUTION: THEORY AND EMPIRICAL EVIDENCE

1.1 Introduction

Labor allocations across production units widely differ across developed and developing countries. In a developed country, a significant fraction of output and employment is accounted for by the right tail of the plant size distribution[1]. However, this feature of the plant size distribution is systematically different in poorer countries. In a developing country, a significant fraction of output and employment is accounted for by a large number of very *small* plants (plants with at most 10 workers). In this paper, I present a model of endogenous managerial skills which accounts for the plant size distribution in a distortion free economy. Then I explore how exogenous differences in aggregate barriers to investment and technology across countries affect the plant size distribution, plant specific productivity and aggregate output.

Plants are on average larger in developed countries compared to developing countries and this is important in the study of economic development because of the following three reasons. Firstly, at the aggregate level, output per worker differs between the richest and poorest countries by a factor of about 30. Secondly, as much as 50% of this difference in output per worker between developed and developing countries can be attributed to total factor productivity[2]. In other words, at the ag-

[1] In this paper I define a production unit as an establishment and measure establishment size by the size of its labor force.

[2] King and Levine (1994), Klenow and Rodriguez-Clare (1997), Prescott (1998) and Halls and Jones (1999).

gregate level, developed countries are more productive than developing countries in producing output. Finally, at the micro level, several empirical studies on plant sizes in developed countries find that large plants are on average more productive than smaller ones[3]. This suggests that there is a link between the plant size distribution, aggregate productivity and aggregate output per worker.

Robinson (1958), Friedman (1967), Kaldor (1934), and Lucas (1978) among others have studied the link between managerial skills and plant size[4]. They recognize that optimum plant size is at least partially determined by fixity of the managerial input. In Lucas (1978) production requires labor, capital, and managerial skills. Individuals choose whether to become a manager or worker depending on their stock of managerial skills, which is exogenous to the model. The production technology is characterized by decreasing returns to scale in the variable factors, labor and capital. This feature of the production function is often referred to as the span-of-control framework.

I present a dynamic span-of-control model with the following twist. I hypothesize complementarities between current managerial skills and investments in managerial quality. In every period, a mass of finitely lived agents are born with some initially endowed levels of managerial skill. These agents are heterogeneous in terms of their initial endowment of managerial skills. The objective of each agent is to maximize lifetime utility from consumption. In the first period of their lives, agents can choose to be either workers or managers. If an agent chooses to be a manager, she can use her managerial skills to operate a plant by employing labor and capital to produce output

[3] Foster, Haltiwanger and Syverson (2008), Leung, Meh and Terajima (2008)

[4] Oi (1983) provides a brief review of this literature.

and collect the net proceeds (after paying labor and capital) as managerial income. Moreover, if the manager chooses to invest in additional skill formation, managerial skills can potentially grow over the life cycle because of skill complementarities. This implies that a manager can grow the size of her plant and managerial income by investing a part of her current income each period in skill formation. In this model, the evolution of managerial skills and hence plant size will depend not only on initially endowed skill but also on skill investment decisions over the life cycle. In equilibrium, managers born with high skills find it optimal to invest more in skills over their lifetime than managers born with low skills. If an agent chooses to be a worker, her managerial skills are of no use and she earns the market wage in every period until retirement. The model delivers an endogenous distribution of skills and plant size for each cohort of managers.

Assuming that the U.S. economy is relatively distortion free, I calibrate the model to match some aggregate and cross sectional features of the U.S. plant data. Then, I compare the performance of the model relative to a number of moments of the data on plant size. I find that my model can capture the critical features of U.S. plant size distribution, including the upper and lower tails. This is critical because on one hand, the upper tail of the size distribution accounts for the bulk of the employment and output in the economy. On the other hand, the lower tail of the size distribution accounts for the bulk of the plants in the economy.

My model provides a natural framework to analyze the effects of aggregate barriers on the plant size distribution, plant size specific productivity, and aggregate output. An aggregate barrier to capital accumulation reflects an increase in a plant's cost of capital rental and is modeled as a proportional tax on the rental price of capital paid by all managers in each period. An aggregate technology barrier is modeled as a fall in the plant level technology parameter which is common across all plants in the country. Recent literature in this area have examined the role of plant specific barriers to investment on plant size distribution, aggregate efficiency, and aggregate output[5]. In this paper, I show that even aggregate barriers (independent of plant size) can have non-trivial effects on the plant size distribution and aggregate output. Aggregate distortions have no effect on the plant size distribution (across steady states) in an otherwise canonical span-of-control model with exogenous managerial skills. In my model, aggregate distortions affect managers in two ways. Firstly, managers react by reducing their demand for capital and labor in each period. Secondly, managers invest less in skill formation over the life cycle because of lower expected return from skill investments. Moreover, in my model, aggregate distortions disproportionately affect managers with higher skills. In particular, high-skill managers cut back on current and future skill investments more than low skilled managers. Hence aggregate barriers disproportionately affect the evolution of plant size of high-skill managers than that of low-skill managers. In the new stationary equilibrium, average plant size falls and new smaller plants mushroom as some workers find it optimal to switch occupations and operate plants as managers.

I use the benchmark model (calibrated to U.S. data) to quantify the effects of aggregate barriers to capital accumulation on the plant size distribution, some mea-

[5] Restuccia and Rogerson (2008), Hsieh and Klenow (2008) and Guner, Ventura, and Xu (2008) among others

sures of productivity and aggregate output. Consider an economy with the following aggregate barrier: All managers pay a 150% tax on the rental price of capital. The standard Lucas (1978) model with exogenous managerial skills predicts that the plant size distribution, average managerial quality, and average managerial productivity will remain unchanged. In my model, the same tax results in a non-trivial effect on plant size distribution, a fall in aggregate output by an additional 4.95 percentage points, and fall in output per worker by an additional 13.5 percentage points, relative to the model with exogenous skills. The same tax on capital rental also reduces average productivity per plant by 4.3% and average managerial quality per plant by 31%. Average plant size falls by about 15.3%, the fraction of *large* plants (plants with more than 100 employees) fall by 17.4%, and the share of employment in these *large* plants fall by about 18.5%. In the same model, the fraction of *small* plants rise by 1.5%, and the share of employment in *small* plants rise by about 19%.

Exogenous differences in the relative price of investment have non-trivial effects on the size distribution of plants. However, these exogenous differences alone cannot account for the variation in the plant size distribution across countries. In the second set of quantitative experiments, I examine whether differences in the relative price of investment along with differences in technology barriers across countries can account for differences in the size distribution of plants across countries. Again, the model with exogenous skills shows no effect on the plant size distribution. However my model implies that differences in the relative price of investment and aggregate productivity across countries can account for a significant fraction of the variation in the plant size distribution across countries[6]. Consider the fraction of *large* plants and the share of employment in these *large* plants across 13 different countries in my sample. The model can account for about 51% of the variation in the fraction of *large* plants and all of the variation in the employment share in these *large* plants. For the same group of countries, consider the fraction of *small* plants and the share of employment in these *small* plants. The skill accumulation model can account for 21% of the variation in the fraction of *small* plants and 40% of the variation in employment share in these *small* plants. Finally the model also accounts for 37% of the variation in the average plant size across the same group of countries.

1.2 **Cross-Country Plant Data**

In this section, I will describe the main features of the plant size data. The purpose of this data set is to provide some evidence of systematic differences in plant size distribution across developed and developing countries. Plant size could be measured by the size of its capital stock or by the size of its labor force. In this paper, I measure plant size by the size of a plant's labor force (number of workers) because of the following two reasons: Firstly it allows easy comparison of cross country data on plant size. Secondly most countries that report plant size census present plant data across employment size categories. I collect industry level data on plant size distribution across 15 developed and developing countries including the U.S. for the year 2004. The data is collected from plant census data reported in each country's official statistical website.

[6] See section 7.

The main feature of my dataset is that it includes plants in the formal as well as the informal sector. This can be quantitatively important because the organization of production differs widely across countries. In particular, the share of informal plants is disproportionately larger in under developed countries. Moreover for any given country, informal plants are more likely to be *small* than *large* in size. Hence, excluding informal plants from the sample could disproportionately effect the plant size distribution in under developed countries. Alfaro, Charton and Kanczuk (2007) use cross country plant level dataset to investigate whether allocation of resources across heterogenous plants are a sufficient determinant of cross country differences in output per worker. The dataset has smaller coverage in poorer countries. To maintain comparability between countries, the study drops all plants in every country employing fewer than 20 employees from the sample. Not surprisingly they find a negative association between average plant size and per capita GDP. I find a positive association between average plant size and GDP in my sample which includes all plants with 1 or more employees. In my sample, more than 85% of all plants in developing countries are *small* (employ less than 10 workers) and on average employ about 60% of the labor force.

In figures B1 through B10, I plot the following features of plant size distribution across per capita GDP (2004) and relative price of investment (2004): average plant size, fraction of *small* plants, share of employment in *small* plants, fraction of *large* plants, employment share in *large* plants.[7]

[7] Table A5 contains a detailed summary of the plant size data across 13 developed and developing countries. Table A5 also contains data on output per worker and relative price of investment data for the same group of countries.

Figure B1 shows a positive relationship between average plant size and per capita GDP. The average plant size in developing countries like India, Bangladesh, Pakistan, and Jordan is at least 3 times smaller than the average plant size in developed countries like Norway or U.S. In figures B2 and B3, I plot the fraction of *large* plants and the employment share in those plants across per capita GDP. I find that more than 46% of U.S. employment is accounted for by *large* plants. In developing and under developed countries like India, Bangladesh and Pakistan, less than 20% of the employment share is accounted for by *large* plants. About 2.5% of plants in the United States are *large* while less than one fifth of 1% of plants in countries like India, Bangladesh, Pakistan and Jordan are *large*. Figures B2-B3 provide evidence that in developed countries, the right tail of the plant size distribution accounts for a bulk of the employment in the economy. In figures B4 and B5, I plot the fraction of *small* plants and the employment share in those plants across per capita GDP. Figures B4 and B5 show that both *small* plants and the share of employment accounted for by *small* plants are bigger in poorer countries than in richer countries in my sample. More than 95% of plants in India, Bangladesh, Pakistan, and Jordan are *small* and they account for more than 55% of the employment in the economy. On the other hand, only 72% of plants in the U.S. economy are *small* but account for only 15% of total employment. Norway, a developed country looks very similar to United States in terms of its plant size distribution. More than 2% of its plants are *large* and account for more than 33% of employment. Like the U.S., small Norwegian plants are far fewer in number and employ a smaller fraction of the labor force compared to countries like India and Bangladesh.

In figures B6 through B10, I investigate how the moments of the plant size distribution vary with differences in the relative price of investments across countries. I compute the ratio of price of investment goods to the price of consumption goods for my sample of countries from the 2004 Penn World Tables[8]. In figure B6, I plot average plant size across relative price of investment. Figure B6 shows a negative relationship between average plant size and relative price of investment. In figure B7, I plot the fraction of *large* plant across the same 15 countries. In figure B8, I plot the employment share of these plants. I find that a country's share of *large* plants is negatively correlated with relative price of investment. Relative price of investment is more than 2.5 times higher in Bangladesh than in the U.S. The fraction of *large* plants is more than 10 times higher in the United States than in Bangladesh. Moreover, the employment share accounted for by these *large* plants is also higher in countries with low relative price of investments than in countries with high relative price of investments. In figure B8, I find that only about 15% of Bangladesh's labor force is employed in *large* plants. The employment share of *large* plants in U.S. is about 47%: almost 3 times higher than Bangladesh. Finally in figures B9 and B10, I plot the fraction of *small* plants and the employment share in those plants across relative price of investment. I find that countries with lower relative price of investments tend to have fewer *small* plants than countries with higher relative price of investments. Moreover, employment share in these *small* plants tend to be higher in high relative price of investment countries than in low relative price of investment countries.

[8] For U.S. I normalize the relative price of investment to one.

1.3 **Related Literature**

My paper is related to the literature which examines the relationship between plant specific distortions and the inefficient allocation of resources across heterogenous production units. Papers like Restuccia and Rogerson (2008), Hsieh and Klenow (2008), Guner,Ventura and Xu (2008) and Alfaro, Charlton, and Kanczuk (2008) examine the effects of plant specific barriers to investments on aggregate productivity and output. Guner et.al. (2008) uses a span-of-control framework to quantitatively evaluate how size-dependent policies affect the size distribution, aggregate efficiency, and output. Unlike Guner et.al. (2008), I incorporate managerial skill investments in the span-of-control framework. Quantitatively, I show that even aggregate barriers to investments (barriers independent of plant size) can affect aggregate output and efficiency through its effects on the overall plant size distribution. This result depends critically on the presence of managerial skill investments and does not hold in an otherwise canonical span-of-control framework without skill investments.

Restuccia et.al (2008) examines the potential effects of idiosyncratic plant specific barriers to investment on aggregate efficiency and output. Restuccia et.al (2008) show how plant specific idiosyncratic distortion both correlated and uncorrelated with plant specific productivity can affect aggregate output and efficiency. In my model, I show that even aggregate barriers to investment (without any explicit plant size specific distortion) can disproportionately affect those plants which are more productive than others. In the real world, plants face both types of barriers to investments. Some barriers are designed to be size dependent while others effect all plants at the same margin. In this paper, I find that aggregate barriers alone can account for a significant fraction of the variation in the plant size distribution across developed and developing countries.

My plant size distribution model is also related to the seminal work by Lucas (1978). The plant size distribution in the model is largely determined by an exogenous distribution of managerial skills. Assuming an exogenous distribution of managerial skills, the model can deliver an endogenous distribution of plant size by allowing individuals to choose occupation. In my paper, I hypothesize complementarities between managerial skills and investments in managerial skill accumulation in the framework. Although initial managerial skill is exogenous in my model, every agent who chooses to be a manager can potentially accumulate additional skills through skill investments. Hence, the distribution of managerial skills and plant size will depend not only on initially endowed skills, but also on skill accumulation decision by managers over the life cycle. By making managerial skills endogenous, the model is able to explain the U.S. plant size distribution, including its upper and lower tails without making any restrictive assumptions on the nature of the initial exogenous skill distribution.

CHAPTER 2

A LIFE-CYCLE MODEL OF PLANT SIZE

2.1 Theoretical Framework

2.1.1 Agents

Consider a T period overlapping generation model where a mass g_i of heterogeneous agents are born each period. The objective of each agent is to maximize the present value of lifetime utility from consumption.

$$\sum_{i=1}^{T} \beta^{i-1} U(c_i) \tag{1}$$

Each agent is born with an initial endowment of managerial skills z_1 drawn from an exogenous distribution with cdf $F(z)$ and density $f(z)$[9]. Moreover every period until retirement (R) each agent is also endowed with one unit of time which she supplies in-elastically as a manager or as a worker. In the very first period agents must choose either to be a worker or a manager. This decision is irreversible. A worker in-elastically supplies her endowed labor time to earn the market wage every period until retirement period R. The decision problem of a worker is to choose how much to consume and save every period, given wages. A manager's problem however is more complicated. A manager has to decide how much labor and capital to employ every period, given factor prices. Every period, she also has to decide how much of the net proceeds (after factor payments) to allocate towards current consumption, savings and investments in skill accumulation.

[9] Subscript denotes the age of the cohort.

2.1.2 Technology

There is a Lucas span-of-control technology. Each plant comprises of a manager with ability z along with inputs labor and capital.

$$y = Az^{1-\gamma}\left(q\left(k,n\right)\right)^{\gamma}$$

where γ is the span-of-control parameter. Every manager can enhance her future skills by investing some of the plant's current proceeds in skill accumulation. The law of motion for managerial skills is given by

$$z^{'} = z + g\left(z,x\right), \quad g_z, g_x > 0$$

where z' is next period's ability and x denotes investment in skill accumulation. The skill accumulation technology described above satisfies two important properties. Firstly the technology shows complementarities between current ability and investments in next period's ability i.e. $g_{zx} > 0$. Secondly $g\left(z,x\right) = 0$ if $x = 0$.

2.1.3 Agent's Decision Problem

I will describe a stationary equilibrium version of the model. Given prices r and w , the objective of each agent born every period is to maximize lifetime utility by choosing to be a worker or a manager. Let $V^m(z_1)$ denote the present value of lifetime utility for a period 1 old manager with initial ability z_1. Let V^w denote the present value of lifetime utility for a period 1 old worker[10]. Let Ω denote an indicator variable

[10] Note that the value of a worker V^w is not a function of endowed managerial skills. I have assumed that managerial skills are of no economic value upon becoming a worker

showing the occupational choice of the agent.

For an agent of type z_1, $\Omega = 1$ if $\max[V^m(z_1), V^w] = V^m(z_1)$. Otherwise $\Omega = 1$. The problem of a one period old agent conditioned on becoming a manager is to choose a sequence of lifetime consumption and savings as a consumer, invest in skills and hire labor and capital inputs each period until retirement as a manager to maximize the present value of lifetime utility from consumption subject to the following constraints:

$$c_i + x_i + s_{i+1} = \pi(r, w, k_i, n_{i,} z_i) + (1 + r)s_i \qquad \forall\ 1 \leq i < R - 1 \tag{2}$$

$$c_i + s_{i+1} = (1 + r)s_i \qquad \forall\ i \geq R \tag{3}$$

$$z'_{i+1} = g\left(z_i, x_i\right) \qquad \forall\ i < R - 1 \tag{4}$$

$$z_1 > 0, s_1 = s_{T+1} = 0$$

where T, is the number of periods in the agent's life, R is the retirement period, r is the rental rate for physical capital, w is the wage rate, z_i is the stock of skill of the i period old manager, s_{i+1} denotes savings in period i, x_i is investment in skill accumulation of the i period old manager in the current period, $\pi(r, w, k_i, n_{i,} z_i) = Az_i^{1-\gamma}\left(q\left(k_i, n_i\right)\right)^{\gamma} - wn_i - (r + \delta)k_i$ is profit of the manager in period i. Equation 4 shows the i period old manager's law of motion for skill accumulation.

The problem of a one period old agent conditioned on becoming a worker is to choose a sequence of lifetime consumption and savings as a consumer, inelastically supply one unit of labor each period until retirement as a worker to maximize the present value of lifetime utility from consumption subject to the following constraints:

$$c_i + s_{i+1} = w + (1+r)s_i \qquad \forall\ 1 \leq i < R-1 \tag{5}$$

$$c_i + s_{i+1} = (1+r)s_i \qquad \forall\ i \geq R \tag{6}$$

$$s_1 = s_{T+1} = 0$$

2.1.4 Market Equilibrium

In a stationary equilibrium, given prices, (r, w), labor, capital and goods market must clear. Moreover every agent must be optimally choosing their occupation to maximize lifetime utility from consumption. Let $\widehat{z}_1$ denote the stock of endowed skill of the marginal manager. Let $k(r, w, z_i)$, $n(r, w, z_i)$, $x(r, w, z_i)$ denote the demand for capital, demand for labor and skill investments by an i period old manager with skill z_i. Let $c^m(r, w, z_i, i)$ and $s^m(r, w, z_i, i)$ denote period i consumption and savings by a i period old manager. Finally let , $c^w(r, w, i)$ and $s^w(r, w, i)$ denote consumption and savings of a i period old worker The labor market equilibrium condition can be written as

$$\sum_{i=1}^{R-1} g_i \int_{\widehat{z}_i^*(\widehat{z}_1^*)}^{\overline{z}_i} n(r^*, w^*, z_i\,(z_1))dF(z_1) = F(\widehat{z}_1^*) \sum_{i=1}^{R-1} g_i \tag{7}$$

where g_i is the total mass of cohorts of age i. The L.H.S. is the labor demand from $R-1$ different cohorts of managers. The R.H.S. is the fraction of each cohort employed as workers times the total mass of all non-retired cohorts in the economy[11]. In the capital market demand for savings is not only generated by managers renting physical capital. There is an additional demand for savings from managers borrowing funds from the capital market to invest in skill accumulation. The capital market equilibrium condition can be written as

$$\begin{aligned}\sum_{i=1}^{R-1} g_i \int_{\widehat{z}_i^*(\widehat{z}_1^*)}^{\overline{z}_i} k(r^*, w^*, z_i(z_1))dF(z_1) \quad = \quad & F_1(\widehat{z}_1^*) \sum_{i=1}^{T-1} g_i s^w(r^*, w^*, i) \\ & + \sum_{i=1}^{T-1} g_i \int_{\widehat{z}_i^*(\widehat{z}_1^*)}^{\overline{z}_i} s^m(r^*, w^*, z_i(z_1), i)dF(z_1) \\ & - \sum_{i=1}^{R-2} g_i \int_{\widehat{z}_i^*(\widehat{z}_1^*)}^{\overline{z}_i} x(r^*, w^*, z_i(z_1))dF(z_1) \qquad (8)\end{aligned}$$

The L.H.S. of the equation 8 above is the capital demand from $R-1$ different cohorts of managers. The first two terms on the R.H.S. is the supply of savings from $T-1$ different cohorts of managers and workers. The third term is the demand for skills investments from $R-2$ different cohorts of managers. Finally, the goods market equilibrium condition requires that the sum of undepreciated capital stock and aggregate output produced in all plants in the economy is equal to the sum of aggregate consumption and savings across all cohorts, and skill investments by all managers across all cohorts.

[11] I assume that all agents must sort themselves into workers and managers in the first period of their lives (period 1) and cannot switch occupations later. Hence $F(\widehat{z}_1)$ denotes the fraction of each cohort who are workers.

Given skill allocations, $\{z_i\}_{i=2}^{R-1}$ for initial age two to age R-1 working cohorts, savings, $\{s_i\}_{i=R}^{T}$ for initial retired cohorts, a stationary competitive equilibrium for this economy is a collection of sequences for agents, $\{c_i^*(z_i)\}_{i=1}^{T}$, $\{s_i^*(z_i)\}_{i=1}^{T}$, $\{x_i^*(z_i)\}_{i=1}^{R-2}$, collection of sequences for plants, $\{k_i^*(z_i)\}_{i=1}^{R-1}$, $\{n_i^*(z_i)\}_{i=1}^{R-1}$ $\forall\ z_i \in [\underline{z},\overline{z}_i]$, a sequence of prices, (r^*, w^*), and a $\widehat{z}_1^*$ such that given (r^*, w^*),

1. Individual Optimization:

   (a) $\{c_i^*\}_{i=1}^{T}$, $\{s_i^*\}_{i=1}^{T}$, $\{x_i^*\}_{i=1}^{R-2}$ solves the agents problem

   (b) The marginal manager born with skill $\widehat{z}_1$ is indifferent between the two occupations, $V^m(\widehat{z}_1) = V^w$

   (c) Agents born with skill greater than $\widehat{z}_1^*$ choose to become managers. Those with skills less than $\widehat{z}_1$ choose to become workers.

2. Plant Optimization:

   $\{k_i\}_{i=1}^{R-1}$, $\{n_i\}_{i=1}^{R-1}$solves the plants problem

3. Labor, capital and goods market clear

2.2 **Model Analysis**

In the model, workers are heterogenous only in terms of their age. The problem of each agent conditioned on becoming a worker is identical to an agent's problem in a standard overlapping generations model. The managers however, are heterogenous in two dimensions: age and skill type. In this section I derive expressions which characterize the manager's problem in two worlds: A world where managerial skills are completely exogenous and a world where managerial skills are endogenous.

2.2.1 Exogenous Skill Model

In the model without skill accumulation, managerial skill remains constant over the life cycle of the agent. Agent's occupational choice and plant size solely depend on their exogenous level of skills. Rewriting the manager's sequential budget constraint 2-3 in present value terms,

$$\sum_{i=1}^{T}\left(\frac{1}{1+r}\right)^{i-1} c_i \leq \sum_{i=1}^{R-1}\left(\frac{1}{1+r}\right)^{i-1} \pi(r, w, k_i, n_i, z_1) \tag{9}$$

Equation 9 above implies that the present value of lifetime consumption for a manager must not be greater than the present value of lifetime net income. The present value of lifetime income is present value of lifetime managerial profits. The objective of the manager is to maximize 1 by choosing consumption, labor and capital allocations each period subject to 9. Taking the first order conditions to the above problem w.r.t labor and capital, I get the following conditions.

$$k_i = (A(1-\alpha)\gamma)^{\frac{1}{1-\gamma}}\left(\frac{\alpha}{1-\alpha}\right)^{\frac{1-\gamma(1-\alpha)}{1-\gamma}}\left(\frac{1}{r+\delta}\right)^{\frac{1-\gamma(1-\alpha)}{1-\gamma}}\left(\frac{1}{w}\right)^{\frac{\gamma(1-\alpha)}{1-\gamma}} z_1 \tag{10}$$

$$n_i = (A(1-\alpha)\gamma)^{\frac{1}{1-\gamma}}\left(\frac{\alpha}{1-\alpha}\right)^{\frac{\alpha\gamma}{1-\gamma}}\left(\frac{1}{r+\delta}\right)^{\frac{\alpha\gamma}{1-\gamma}}\left(\frac{1}{w}\right)^{\frac{1-\alpha\gamma}{1-\gamma}} z_1 \tag{11}$$

Substituting the value of labor and capital from equations 10 and 11 into the production function, I get,

$$\pi_i = A(1-\gamma)\left(A(1-\alpha)\gamma\right)^{\frac{\gamma}{1-\gamma}} \left(\frac{\alpha}{1-\alpha}\right)^{\frac{\alpha\gamma}{1-\gamma}} \left(\frac{1}{r+\delta}\right)^{\frac{\alpha\gamma}{1-\gamma}} \left(\frac{1}{w}\right)^{\frac{\gamma(1-\alpha)}{1-\gamma}} z_1 \tag{12}$$

From equations 10-11 it is clear that optimal labor and capital demands each period are linear functions of endowed managerial skill z_i. The above equations show that the size of a manager's plant and managerial income depend on her initially endowed skills. Rewriting equation 9 using equation 12 I get,

$$\sum_{i=1}^{T}\left(\frac{1}{1+r}\right)^{i-1} c_i \leq \sum_{i=1}^{R-1}\left(\frac{1}{1+r}\right)^{i-1} \pi(r,w,z_1)$$

The only remaining problem for the manager of type z_1 is to choose lifetime consumption to maximize lifetime utility subject to the above constraint. This implies that $V^m(z_1)$ is monotonically increasing in z_1. Hence all agents will exogenous skills less than $\widehat{z}_1$[12] become workers and the rest become managers.

2.2.2 Skill Accumulation Model

The workers problem in the skill accumulation model is identical to the workers problem in the model without skills. The manager's problem however is different. With skill complementarities, agents upon becoming managers can operate plants of a given size and make it grow over time by investing in managerial skills. Rewriting the manager's sequential budget constraint 2-3 in present value terms,

[12] where, $V^m(\widehat{z}_1) = V^w$

$$\sum_{i=1}^{T}\left(\frac{1}{1+r}\right)^{i-1} c_i \leq \sum_{i=1}^{R-1}\left(\frac{1}{1+r}\right)^{i-1} \pi(r, w, k_i, n_{i,} z_i) - \sum_{i=1}^{R-2}\left(\frac{1}{1+r}\right)^{i-1} x_i \qquad (13)$$

Equation 13 implies that the present value of lifetime consumption for a manager must not be greater than the present value of lifetime net income. The R.H.S. of the above equation is the present value of lifetime managerial profits less present value of lifetime investments in skill accumulation. The objective of the manager is to maximize 1 by choosing consumption, skill investments, labor and capital allocations each period subject to equation 13 and the skill accumulation technology 4. Using the first order conditions with respect to labor and capital I can rewrite 13 in reduced form[13].

$$\sum_{i=1}^{T}\left(\frac{1}{1+r}\right)^{i-1} c_i \leq \sum_{i=1}^{R-1}\left(\frac{1}{1+r}\right)^{i-1} \pi^*(r, w, z_i) - \sum_{i=1}^{R-2}\left(\frac{1}{1+r}\right)^{i-1} x_i$$

The remainder of the manager's problem can be solved in the following two steps: (i) choose life time skill investments to maximize the present value of lifetime income (R.H.S. of the above equation) and (ii) Choose lifetime consumption allocations to maximize lifetime utility from consumption.

Consider the manager's inter temporal decision rule for skill investment. In the model with skill complementarities, the manager has two ways to invest: Invest in the capital market at the market rate of interest r or invest to enhance her own managerial skills next period and earn higher profits.

[13] I assume the following functional form for the skill accumulation technology: $z' = z + z^{\theta_1} x^{\theta_2}$

$$\beta U'(c_{i+1})(1+r) = \beta U'(c_{i+1})\pi_z\,(r,w)\,g_x(z_i,x_i)$$

The L.H.S. of the above equation is next period's gain in utility from one unit of current savings. The term $g_x(z_i, x_i)$ on the R.H.S. is the additional skill generated next period from an additional unit of investments in skills in the current period. $\pi_z\,(r,w)$ is the additional profit generated from an additional unit of managerial skills[14]. Hence the R.H.S. is the gain in utility by the i year old manager from investing one unit of the current consumption good in skill accumulation. To get a unique interior optimum g_{xx} must be negative. This implies that the marginal benefit of investing in skill accumulation is monotonically decreasing in the level of skill investment while the marginal cost is constant. The above equation along with the second order condition implies that

$$x_i^* = x(r,w,z_i) \tag{14}$$

and that x_i^* is an interior optimum. Using backward induction, equation 14 along with equation 4 implies that $x_i^* = X_i(r,w,z_1)\ \forall\ i < R-1$ and $z_i^* = Z_i(r,w,z_1)\ \forall\ i < R$ where z_1 denotes endowed managerial skills of a new born agent. Given prices, optimal stock of managerial skill each period until retirement is a function of endowed period 1 managerial skill z_1. Using the above conditions, I can rewrite the manager's lifetime budget constraint in reduced form as

[14] $\pi\,(r,w,z)$ is linear in z. Hence $\pi_z = \pi_z\,(r,w)$.

$$\sum_{i=1}^{T}\left(\frac{1}{1+r}\right)^{i-1}c_i \leq \sum_{i=1}^{R-1}\left(\frac{1}{1+r}\right)^{i-1}\pi^*(r,w,Z_i(r,w,z_1)) - \sum_{i=1}^{R-2}\left(\frac{1}{1+r}\right)^{i-1}X_i(r,w,z_1)$$

The only remaining decision is to choose a sequence of lifetime consumption subject to the budget constraint above to maximize the present value of lifetime utility. Using the reduced form of the manager's lifetime budget constraint, and the decision rule for skill investments, it is easy to check that the present value of the manager's lifetime income, $V^m(z_1)$ is monotonically increasing in z_1. Hence all new born agents with exogenous skills less than $\widehat{z}_1$ become workers, the rest become managers.

2.3 Effects of Aggregate Barriers: A Qualitative Analysis

In a standard one sector growth model one can analyze the effects of aggregate productivity and aggregate barriers to capital accumulation on aggregate output. My model provides a natural framework to analyze the effects of exogenous differences in productivity and aggregate barriers to capital accumulation not only on aggregate output but also on the plant size distribution. In this section, I will qualitatively examine the effect of two types of distortions: aggregate barriers to capital accumulation and aggregate productivity. The qualitative effect of these barriers will be studied in a model with and without skill accumulation. I model barriers to capital accumulation as a proportional tax on capital rental faced by all plants in a given country[15]. Aggregate productivity enters the model through the plant level technol-

[15] The revenue collected for the tax is returned as an equal lump sum transfer to every agent.

ogy parameter common to all plants in a given country. It is used to capture the effects of exogenous productivity differences across countries on the plant size distribution. The two distortions described above enter the profit function of every manager in the following way:

$$\pi_i = A_j z_i^{1-\gamma} \left(q\left(k,n\right)\right)^{\gamma} - wn_i - (1+t_j)(r+\delta)k_i \tag{15}$$

where, A_j is plant level productivity parameter common across all plants in country j, t_j is the tax rate on capital rental in country j. Labor demand, capital demand and managerial profits are similar to equations 10-12 with an additional country specific tax and productivity term.

$$k_i = \left(\frac{1}{1+t_j}\right)^{\frac{1-\gamma(1-\alpha)}{1-\gamma}} A_j^{\frac{1}{1-\gamma}} \left((1-\alpha)\gamma\right)^{\frac{1}{1-\gamma}}$$

$$\left(\frac{\alpha}{1-\alpha}\right)^{\frac{1-\gamma(1-\alpha)}{1-\gamma}} \left(\frac{1}{r+\delta}\right)^{\frac{1-\gamma(1-\alpha)}{1-\gamma}} \left(\frac{1}{w}\right)^{\frac{\gamma(1-\alpha)}{1-\gamma}} z_i \tag{16}$$

$$n_i = \left(\frac{1}{1+t_j}\right)^{\frac{\alpha\gamma}{1-\gamma}} (1-\gamma) A_j^{\frac{1}{1-\gamma}} \left((1-\alpha)\gamma\right)^{\frac{1}{1-\gamma}}$$

$$\left(\frac{\alpha}{1-\alpha}\right)^{\frac{\alpha\gamma}{1-\gamma}} \left(\frac{1}{r+\delta}\right)^{\frac{\alpha\gamma}{1-\gamma}} \left(\frac{1}{w}\right)^{\frac{1-\alpha\gamma}{1-\gamma}} z_i \tag{17}$$

$$\pi_i = \left(\frac{1}{1+t_j}\right)^{\frac{\alpha\gamma}{1-\gamma}} A_j^{\frac{1}{1-\gamma}} (1-\gamma) \left((1-\alpha)\gamma\right)^{\frac{\gamma}{1-\gamma}}$$

$$\left(\frac{\alpha}{1-\alpha}\right)^{\frac{\alpha\gamma}{1-\gamma}} \left(\frac{1}{r+\delta}\right)^{\frac{\alpha\gamma}{1-\gamma}} \left(\frac{1}{w}\right)^{\frac{\gamma(1-\alpha)}{1-\gamma}} z_i \tag{18}$$

From the above equations it is clear that the qualitative effects of productivity and aggregate barriers to capital accumulation will be identical. Hence in the following subsection I will only analyze the qualitative effect of aggregate barriers to capital accumulation in a model with and without skill accumulation.

2.3.1 Exogenous Skill Model

From equations 16-17 it is clear that the tax affects every manager at the intensive margin. Given factor prices, the tax also has an effect on the extensive margin. Given prices, some managers find that the present value of their life time managerial income is less than the present value of lifetime income from being a worker. This makes some managers switch occupation and become a worker. Hence given prices, the tax increases the aggregate supply of labor and reduces the aggregate demand for labor at the same time. However, in the new stationary equilibrium, the tax has no effect on the aggregate demand for labor. The market wage falls such that in the new stationary equilibrium all plants hire the same number of workers as they did before the tax was imposed[16]. Hence the plant size distribution does not change as a result of a capital rental tax in a model without skill accumulation. In the new equilibrium, However, each plant rents a smaller stock of capital. Both aggregate capital output ratio and aggregate output fall.

[16] See appendix C for details.

2.3.2. Skill Accumulation Model

In the skill accumulation model, the capital rental tax effects managers on the intensive as well as the extensive margin. On the intensive margin, given managerial skills, the effect of the tax on factor demands are identical to the skill accumulation model. However unlike the exogenous skill model, the capital rental tax affects managers on the extensive margin in two different ways. Firstly, like the exogenous skill model, given prices, some marginal managers now find it optimal to switch occupation and become workers. Secondly, existing managers react to the capital rental tax by investing less in skills over the life cycle. Consider a two period version of the model. Using equation 18, the decision rule for skill investments can be rewritten as

$$\beta U'(c_2)(1+r) = \beta U'(c_2)\pi_z\left(r, w, t_j\right) g_x(z_1, x_1)$$

A higher tax reduces the marginal benefit of skill investments for any given manager type z_1 (R.H.S. of the above equation). Optimal investment in skills fall. Differentiating the above equation with respect to the tax rate, I get

$$\frac{\partial x_1}{\partial t} = -\frac{\pi_{zt}}{\pi_z}\frac{g_x(z_1, x_1)}{g_{xx}(z_1, x_1)}$$

From the expression above it is clear that the marginal effect of the tax on skill investments is negative since $g_x > 0$, $g_{xx} < 0$ and $\pi_{zt} < 0$. Moreover the marginal effect of the tax on skill investments also depend on endowed managerial skills. Substituting the functional form of the skill accumulation technology[17] into the expression above

[17] $z' = z + z^{\theta_1} x^{\theta_2}$

I get:

$$\frac{\partial x_1}{\partial t} = -\frac{\alpha\gamma}{(1-\gamma)}\frac{1}{1-\theta_2}\left(\frac{1}{1+t}\right)^{\left(1+\frac{\alpha\gamma}{(1-\gamma)(1-\theta_2)}\right)} A_x z_1^{\frac{\theta_1}{1-\theta_2}}$$

where $A_x = \left(\frac{\theta_2 A_\pi}{1+r}\right)^{\frac{1}{1-\theta_2}}$ and $A_\pi = A(1-\gamma)\left(A(1-\alpha)\gamma\right)^{\frac{\gamma}{1-\gamma}}\left(\frac{\alpha}{1-\alpha}\right)^{\frac{\alpha\gamma}{1-\gamma}}\left(\frac{1}{r+\delta}\right)^{\frac{\alpha\gamma}{1-\gamma}}\left(\frac{1}{w}\right)^{\frac{\gamma(1-\alpha)}{1-\gamma}}$. The above derivative implies the marginal effect of the tax on skill investments is higher for managers born with high skills than for managers born with low skills. The capital rental tax also has a growth effect on managerial skills. For any given manager, consider the ratio of managerial skills in the two periods:

$$\frac{z_2}{z_1} = 1 + (\theta_2 A_\pi)^{\frac{\theta_2}{1-\theta_2}}\left(\frac{1}{1+t}\right)^{\frac{\alpha\gamma\theta_2}{(1-\gamma)(1-\theta_2)}} z_1^{\frac{\theta_1+\theta_2-1}{1-\theta_2}}$$

The above expression implies that the capital rental tax has a negative effect on the growth of managerial skills between any two consecutive periods. Moreover, the marginal effect of the tax on the growth rate is also a function of endowed managerial skills. In particular, if the skill accumulation technology shows increasing returns to scale $(\theta_1 + \theta_2 - 1)$, then the tax disproportionately affects the growth rate of high-skill managers. Hence, the tax not only reduces aggregate output and the aggregate capital stock but also affects the overall plant size distribution in the economy.

CHAPTER 3

QUANTITATIVE ANALYSIS: INTEGRATING THEORY AND EMPIRICAL EVIDENCE

3.1 Parameter Choice and Calibration

My objective is to compare and contrast the results of my skill accumulation model relative to an otherwise canonical Lucas (1979) span-of-control model without skill accumulation. In particular I want to evaluate how the skill accumulation model performs relative to the exogenous skill model on two frontiers: (i) explaining plant size distribution in an undistorted economy and (ii) quantifying the effects of aggregate barriers on aggregate and cross sectional features of the plant size distribution. In light of this objective I will calibrate two versions of my model: A model with managerial skill accumulation and a model without managerial skill accumulation. Hence, in each of the two calibration exercises, I assume the U.S. economy to be distortion free and calibrate model parameters to match some important aggregate and cross sectional features of the U.S. plant data. Before discussing the calibration strategy in each of the two models, let me first describe some important features of the U.S. plant size data collected from the 2004 U.S. Economic Census. The average size of a plant in the U.S. was 17.86. As many as 72.5% of plants in the economy employed less than 10 workers but accounted for only 15% of the total employment. Less than 2.7% of plants employed more than 100 employees but accounted for about 46% of total employment.

In the model with skill accumulation, I assume the following functional form for the plant level production technology and the skill accumulation technology.

$$
\begin{aligned}
z\prime &= z + g(z,x) = z + z^{\theta_1} x^{\theta_2} \\
y &= A z^{1-\gamma} \left(k^{\alpha} n^{1-\alpha}\right)^{\gamma}
\end{aligned}
$$

The exogenous skill distribution of new born agents in the model is assumed to follow a log normal distribution with parameters μ and σ. I let the model period correspond to 10 years. Each cohort of agents enter the model at age 20 and live for T=80 years. There are a total of 9 parameters in the skill accumulation model listed in tables A1 and A2. The product of two of these parameters: importance of capital (α) and returns to scale (γ) determine the share of capital in output. I determine the values of capital share in output and the depreciation rate from the data. A measure of capital consistent with my model on business plants should include capital accounted for by the business sector. Similarly a measure of output consistent with my definition of capital should only include output accounted for by the business sector. The measure of capital and output discussed in Guner et.al. (2008) is consistent with my plant size distribution model. Hence I adopt the value of capital output ratio, capital share and depreciation rate reported in Guner.et.al. (2008). I choose the population growth rate in my model such that the annual population growth rate is 1.1%.

After calibrating the depreciation rate, capital share in output and the population growth rate, I have 6 more parameters to calibrate: returns to scale, discount factor, two parameters of the skill accumulation technology and the mean and variance of the skill distribution. At the aggregate level, I want the benchmark model to replicate the capital output ratio in the U.S. economy. At the cross sectional level, the model implied distribution of plants should capture some of the important features of the U.S. plant size distribution discussed in the beginning of this section. I normalize the mean of the skill distribution to zero since it does not determine the capital output ratio or the distribution of plants. I jointly calibrate the 5 remaining parameters (listed in table A2) to match the following 5 moments of the U.S. plant size distribution: Mean plant size, fraction of plants with less than 10 workers (*small* plants), fraction of plants with more than 100 workers (*large* plants), fraction of the labor force employed in large plants and the aggregate capital output ratio.

In the case of the exogenous skill model, I also assume the U.S. economy to be distortion free and calibrate the exogenous skill model to match some aggregate and cross sectional moments of U.S. plant size data in steady state. The measure of capital share in output, population growth rate and depreciation rate are identical to the skill accumulation model. The model without managerial skills has two parameters fewer than the skill accumulation model. The two skill accumulation technology parameters are missing from the exogenous skill model. I normalize the mean of the skill distribution to zero. I choose the 3 remaining parameters (returns to scale, discount factor and the variance of the skill distribution) to match the following 3 moments of the U.S. plant size distribution: Mean plant size, fraction of plants with less than 10 workers, and the aggregate capital output ratio. Table A2 reports the calibrated parameter values of the two calibration exercises. In table A3, I reproduce the targets of the calibration.

3.2 Model Performance

The skill accumulation model is successful in replicating multiple features of the U.S. plant size distribution. At the same time, the model without skill accumulation has serious limitations. The coefficient of variation of the plant size distribution implied by the skill accumulation model is 4.05 which is close to the corresponding value (3.98) in the data. However, the coefficient of variation in the model without skill accumulation is 2.42: 40% lower that its empirical counter part. This implies that by introducing skill accumulation in an otherwise canonical Lucas (1978) span-of-control framework, the model is able to replicate the entire plant size distribution fairly well. In figures B11 and B12, I plot some additional moments of the plant size distribution and employment share distribution predicted by my model. In figure B12, I plot the plant size distribution across 7 different employment size classes predicted by the skill accumulation model, exogenous skill model and the corresponding observed values from the data. In figure B11, I plot employment share distribution across 6 different employment size classes predicted by my model and the corresponding observed values from the data. Figure B12 shows that the model with endogenous skills closely matches the plant size distribution across all size classes. The success of the skill accumulation model in explaining the tail of the plant size distribution is quantitatively important because more than 45% of employment in the U.S. economy is accounted for by plants with over 100 employees. From figure B11, I find that the skill accumulation model also predicts the employment share distribution across all size classes. Consider the calibrated value of the parameter governing the manager's share in output $(1-\gamma)$. The value implied by the skill accumulation model is close to the value reported in the literature. The value of the parameter implied by the exogenous skills model is way below the value reported in the literature

3.3 **Counterfactual Experiment**

In this section I will evaluate the effects of aggregate barriers to capital accumulation and aggregate productivity on aggregate output, productivity, occupational choice, and some cross sectional features of the plant size distribution. I will also evaluate how the skill accumulation model performs relative to a model with exogenous skills. In section 3.3.1, I will evaluate the effects of distortions in the relative price of investment across countries on the economy. In section 3.3.2, I will analyze the effects of exogenous differences in aggregate productivity across countries. I consider the following three measures of productivity: average output per plant, average managerial quality, and average plant productivity. These measures are defined as: Average output per plant or average output per manager is defined as

$$\frac{\sum_{i=1}^{R-1} g_i \int y\left(z_i(z_1)\right) dF(z_1)}{(1-F(\widehat{z}_1)) \sum_{i=1}^{R-1} g_i}$$

where $(1-F(\widehat{z}_1)) \sum_{i=1}^{R-1} g_i$ is the total number of plants or managers in the economy in steady state and $\sum_{i=1}^{R-1} g_i \int y\left(z_i(z_1)\right) dF(z_1)$ denotes aggregate output. Average managerial quality is defined as

$$\frac{\sum_{i=1}^{R-1} g_i \int z_i(z_1) dF(z_1)}{(1 - F(\widehat{z}_1)) \sum_{i=1}^{R-1} g_i}$$

where $\sum_{i=1}^{R-1} g_i \int z_i(z_1) dF(z_1)$ denotes aggregate managerial quality. Finally average plant productivity is defined as

$$\frac{\sum_{i=1}^{R-1} g_i \int (z_i(z_1))^{1-\gamma} dF(z_1)}{(1 - F(\widehat{z}_1)) \sum_{i=1}^{R-1} g_i}$$

where $\sum_{i=1}^{R-1} g_i \int (z_i(z_1))^{1-\gamma} dF(z_1)$ is defined as the aggregate plant productivity.

3.3.1 Aggregate Barriers to Capital Accumulation

In section 1.2, I provided some evidence of systematic differences in plant size distribution across countries with high and low relative price of investment. In countries with low relative price of investment, a significant fraction of employment and output is generated by *large* plants. Quite the opposite was true for countries with high relative price of investment. In the model, a high relative price of investment (relative price greater then unity) appears in the profit function of the manager (equation 15) as a proportional tax on capital rental. In the sample, relative price of investment ranges from 1 for the U.S. to 2.7 for Bangladesh[18]. In the model this is equivalent to a tax on capital rental ranging from 0 to 170%. In table A6, I evaluate the following

[18] The relative price of investment for Uganda is a 7.17 which is probably an outlier. See table A5.

two cases: a 100% tax on capital rental and a 150% tax on capital rental. In a closed economy, the incidence of the tax are partly borne by households and partly borne by managers operating plants. In the case of a small open economy, the capital market is perfectly elastic and the entire burden of the tax is borne by managers. The quantitative effects of the tax are expected to be larger in an open economy than in the case of a closed economy. In the discussion below I will enumerate the quantitative effects of the tax on moments of the size distribution, productivity, and aggregate statistics.

3.3.1.1 Effects on Plant Size: A capital rental tax has no effects on the plant size distribution in the model without skill accumulation. In the case of a closed economy, a 100% capital rental tax in the skill accumulation model resulted in the following changes to the plant size distribution: a 7.4% fall in the mean plant size from 17.6 to 16.3, a 7% fall in the share of employment accounted for by *large* plants (employing 100 or more employees), a 7.68% rise in employment share in *small* plants (employing 10 or fewer employees), a 7.8% fall in the number of *large* plants, and a 1.2% rise in the number of *small* plants. Consider the effects of the same tax in a small open economy with a perfectly elastic capital market. The effects of the tax on the moments of the plant size distribution are larger in a small open economy compared to the closed economy. A 100% capital rental tax in the skill accumulation model reduced the mean plant size by 12% which is 62% higher than that in the closed economy. The share of employment accounted for by *large* plants fell by 14% which is twice as that in the closed economy. The same tax increased employment share in *small* plants by 14.4% which is about 88% higher compared to the closed economy. The number of *large* plants increased by 13.6% which is about 74% higher compared to the closed economy. Finally, the same tax also increased the number of *small* plants by 1.4% which is about 16% higher compared to the closed economy. In the fourth and fifth column of the same table, I compare the results of a 150% tax on capital rental in the case of a closed and an open economy. A 150% capital rental tax in the skill accumulation model reduced mean size by 9.7% in the closed economy and 15.3% in the open economy. The same tax reduced employment share in *large* plants by 10% in the closed economy and by 18.5% in the open economy. The 150% tax on capital increased employment share in *small* plants by 11% in a closed economy and by 19% in an open economy. The share of *large* plants in the economy fell by 10.9% in a closed economy and by 17.4% in an open economy. Finally, the share of *small* plants increased by 1.5% in a closed economy and by 1.8% in an open economy.

3.3.1.2 Effects on Productivity: Consider the effects of a capital rental tax on output per plant in a model with and without managerial skill accumulation. In the closed economy case, the 100% capital rental tax reduced output per plant by 30.2% which is 6.2% more than the fall in output per plant in the model without skill accumulation. In the case of an open economy, the same tax reduced output per plant by 40.4% which is 12% more than the fall in output per plant in the model without skill accumulation. In the closed economy case, the 150% capital rental tax reduced output per plant by 38.8% which is 7.8% more than the fall in output per plant in the model without skill accumulation. In the case of an open economy, the same tax reduced output per plant by 49.2% which is 13.5% more than the fall in output per plant in the model without skill accumulation. A capital rental tax has no effects on average managerial quality or average productivity per plant in the model with exogenous skills. In the skill accumulation model, a 100% tax on capital rental reduces average managerial quality by 14% in the case of a closed economy and 25% and an open economy. A 150% tax on capital rental reduces average managerial quality by 19.2% in the case of a closed economy and by 31% in the case of an open economy. Finally, consider the effects of a capital rental tax on average productivity per plant. A 100% tax on capital rental reduces productivity per plant by 2.4% in a closed economy and by 4.3% in the case of an open economy. A 150% tax on capital rental reduces productivity per plant by 3.3% in the case of a closed economy and by 5.5% in the case of an open economy.

3.3.1.3 Effects on Aggregate Statistics: Consider the effects of a 100% tax on capital rental on aggregate output and the occupational choice of agents. In the case of an open economy, aggregate output falls by 28.4% in the model with exogenous managerial skills. The same tax reduces aggregate output by an additional 4.4% in the model with managerial skill accumulation. In a closed economy, aggregate output falls by 24% in the model with exogenous managerial skills. The same tax reduces aggregate output by an additional 1.2% in the model with managerial skill accumulation. Hence, the capital rental tax has a bigger effect on aggregate output in the skill accumulation model than in the model with exogenous skills. The tax has no effect on occupational choice of agents in the model with exogenous skills. Hence, the fraction of workers and managers in the model remain unchanged. In the skill accumulation model, the same tax has an effect on the extensive margin. In the case of a closed economy, the tax reduces the fraction of workers by 0.42% from 94.6

to 94.2. The effects of the tax on occupational choice is slightly higher in the case of an open economy. The tax reduces the fraction of managers by 0.74% from 94.6 to 93.9. Consider the effects of a 150% tax on capital rental on aggregate output and the occupational choice of agents. In the case of an open economy, aggregate output falls by 35.75% in the model with exogenous managerial skills. The same tax reduces aggregate output by an additional 4.95% in the model with managerial skill accumulation. In a closed economy, aggregate output falls by 30.96% in the model with exogenous managerial skills. The same tax reduces aggregate output by an additional 1.74% in the model with managerial skill accumulation.

3.3.2 Exogenous Productivity Differences

In this section, I will examine the potential effects of exogenous changes in aggregate productivity on the plant size distribution, aggregate output, and cohort specific productivity measures. Exogenous changes in aggregate productivity have no effect on the plant size distribution in a model without skill accumulation. In the model with managerial skill complementarities, aggregate productivity not only changes the plant size distribution but also generates cohort specific productivity effects.

3.3.2.1 Effects on Plant Size: In table A7, I summarize the results of exogenous changes in productivity on the plant size distribution. In a closed economy, a 50% fall in productivity across all plants reduces mean size by 27% from 17.6 to 12.84. The fraction of *large* plants fall by 34.5% and the employment share in *large* plants fall by 37.6%. The fraction of *small* plants rise by 3.4% and the employment share in *small* plants rise by 38.8%. A 75% fall in the same productivity parameter reduces mean size by 39.2% from 17.6 to 10.7. The fraction of *large* plants fall by 57.8% and the employment share in *large* plants fall by 63.8%. The fraction of *small* plants rise by 5.4% and the employment share in *small* plants rise by 66.6%. In the case of an open economy, exogenous changes in aggregate productivity have slightly higher effects on the moments of the plant size distribution.

3.3.2.2 Effects on Productivity: In the exogenous skills model, a 75% fall in aggregate productivity in a closed economy, reduces average output per plant by 87.2%. across all cohorts. In table A8, I summarize the effects of the same exogenous decline in productivity in a closed economy with skill complementarities. Average output per plant for all cohorts fall by 93.3% which is 6.1% more than that in the exogenous skill model. After breaking down the statistic by cohort, I find that output per plant falls by 96.2% for the oldest cohort of managers. For the youngest cohort of managers, output per plant falls by 85.5%. Hence, productivity per plant falls by about 10% more in the oldest cohort than in the youngest cohort of managers. Similarly, a fall in aggregate productivity has a bigger effect on average managerial ability and average productivity per plant for older cohorts of managers than for younger ones in the model with skill complementarities. Average managerial ability for all cohorts fall by 69.3%. For the oldest cohort of managers[19], average managerial ability falls by 82% and by 28.7% for the youngest cohort of managers. Hence, average managerial ability falls by an additional 53.7 percentage points in the oldest cohort than in the youngest cohort of managers. Finally, average managerial productivity falls by 15.9% for all managers, 25% for the oldest cohort, and by 8.7% for the

[19]Since agents retire at age 5 in the model, I refer to age 4 managers as oldest working cohorts.

youngest cohort.

3.3.2.3 Effects on Aggregate Statistics: In the exogenous skills model, exogenous changes in aggregate productivity have no effects on the occupational choice of agents. Hence the fraction of managers and workers in the economy remains unchanged. In the model with skill complementarities, a 50% fall in aggregate productivity reduces the number of workers in the economy by 1.9% from 94.6% to 92.8%. In the same model, a 75% fall in aggregate productivity reduces the number of workers by 3.4%. In the case of an open economy, the effects on occupational choice are slightly higher. In the exogenous skills model, a 50% fall in aggregate productivity reduces aggregate output by 64.2% in a closed and an open economy. In the model with skill complementarities, the same decline in aggregate productivity reduces aggregate output by 68.3% in a closed economy and by 69.6% in an open economy. Similarly, the effects of the 75% fall in aggregate productivity are higher in the model with skill complementarities than in the model with exogenous skills. In particular, aggregate output falls by an additional 2.2 percentage points in the closed economy case and by an additional 2.9 percentage points in the open economy case. In the model, capital output ratio for each plant depends on the rental rate for physical capital but is independent of the manager's skill or the wage rate. Hence, in an open economy, exogenous changes in the aggregate productivity have no effects on the aggregate capital output ratio. In a closed economy, a 50% and a 75% fall in aggregate productivity increases the aggregate capital output ratio by 6.9% and 12.5% respectively.

3.3.3 Aggregate Barriers and Plant Size Variation

In the above two sections, I found that exogenous differences in the relative price of investment or exogenous changes in productivity have non-trivial effects on the size distribution of plants in a skill accumulation model. I this section I will examine whether exogenous differences in the relative price of investment along with exogenous differences in productivity across countries can account for differences in the size distribution of plants across countries. I will first describe the experiment for two countries: U.S. and India. Then I will repeat the experiment for all countries in my sample. Output per worker in India is about 10% of that of U.S. About 27.2% of the gap between the two countries can be explained by distortions in the relative price of investment in India. Hence, about 72.8% of the gap in output per worker is unaccounted for by the skill accumulation model. In this section, I will attribute the remaining gap in output per worker between the two countries to differences in the plant level productivity between the two countries such that:

$$\frac{\text{Output per Worker }|_{\text{India }(A=A_I,t_I=94\%)}}{\text{Output per Worker }|_{\text{U.S. }(A=1,t_I=0)}} = \frac{\text{Output per Worker }|_{\text{India }(data)}}{\text{Output per Worker }|_{\text{U.S. }(data)}}$$

where A_I is the productivity parameter common across all plants in India and t_I is the capital rental tax in India. In figure B13, I plot the cumulative distribution function of the employment share distribution for India and U.S. generated by the skill accumulation model. I also plot the Indian data in the same graph. I find that the U.S. employment share distribution implied by the model first order stochastically dominates the Indian employment share distribution implied by the model. In the skill accumulation model, a combination of capital rental tax and low productivity causes a systematic reallocation of the labor force from larger plants to smaller ones. The cumulative distribution function of Indian employment implied by the model, for the most part, lies between the cumulative distribution function of Indian employment and the the cumulative distribution function of U.S. employment. This implies that aggregate barriers in the model with skill complementarities can partly account for the India employment share distribution. In figure B14, I plot the cumulative distribution function of the plant size distribution for India and U.S. generated by the skill accumulation model. I also plot the Indian data in the same graph. I find that the U.S. plant size distribution implied by the model first order stochastically dominates the Indian plant size distribution implied by the model. However, the skill accumulation model under estimates the effect of aggregate distortions on the plants size distribution. For example, consider the fraction of *small* plants (employing less than 10 employees) observed in the Indian data and predicted by the skill accumulation model in figure B14. The skill accumulation model under estimates the fraction of *small* plants (under 10 employees) by about 21 percentage points. In India about 96% of plant employ less than 10 employees. The skill accumulation model estimates the fraction of *small* plants in India to be about 75%. (About 4 percentage points higher than the U.S.). In table A9, I examine the explanatory power of the model to replicate the data on the fraction of plants and the employment share in India across two size classes: *small* and *large*. As much as 92.6% of the gap in employment share in *large* plants between U.S. and India can be accounted for by the model with skill complementarities. For the same two countries, the model also explains 26.5% of the gap in employment share in *small* plants, 58.4% of the gap in the fraction of *large* plants, and 14.4% of the gap in the fraction of *small* plants.

The skill accumulation model also has some interesting implications for the differences in the evolution of plant size between the two countries. In table A10, I report the fraction of each cohort of managers who operate *large* plants (100 or more employees) in each country implied by the skill accumulation model. In the U.S., I find that no managers between 20 and 30 years of age operate *large* plants while more than 8% of managers between 50 an 60 years of age operate *large* plants. On the other hand, in India 0.11% of managers between ages 20 and 30 operate *large* plants while only 1.53% of managers between ages 50 and 60 operate *large* plants. Compared to the U.S., very few managers in India accumulate enough skills during their life time to operate *large* plants. In table A11, I report the fraction of each cohort of managers who operate *small* plants (10 or less employees) in each country. In the U.S about 84% of managers between ages 20 and 30 operate *small* plants, but only 55% of managers between ages 50 and 60 operate *small* plants. On the other hand, 78% of Indian managers between ages 20 and 30 operate *small* plants and about 73% of managers between ages 50 and 60 operate *large* plants.

I will repeat the U.S.-India experiment for every country in my sample. In particular, I will calibrate the plant level production technology for each country j such that the existing relative price differences across countries can account for differences in output per worker across countries. For each pair (A_j, t_j), I will compare the following features of the plant size distribution across countries: fraction of plants with less than 10 employees, fraction of plants with 100 or more employees, share of employment in *small* plants, share of employment in *large* plants and the mean plant size.

In figures B15-B19, I plot the data on the above five moments against the values implied by the model for each of the 10 countries in my sample. In each figure, I also overlay the linear regression line between the data and the model and report the R-Square values. In figure B15, I find that the correlation between the data on employment share in large plants and its corresponding model statistic is 0.7. In figure B16, I plot the data on fraction of large plants and its corresponding values implied by the model. The linear regression line shows a correlation of 0.17. In figure B17, I plot employment share in small plants implied by the model and observed in the data. For small plants, the correlation between the data and the model statistic is 0.4. In figure B18, I plot the fraction of small plants implied by the model and observed in the data. The correlation between the data and the model statistic is 0.08. Finally in figure B19, I plot the average plant size implied by the model against the data on average plant size. The correlation between the two variables is 0.19.

In table A12, I report the coefficient of variation for each of the 5 moments implied by the skill accumulation model and the corresponding values from the data. I find that the model can account for 40% and 116% of the variation in the share of employment in *small* and *large* plants respectively. The model can also account for about 50% of the variation in the fraction of *large* plants and 21% of the variation in the fraction of *small* plants. Finally, the skill accumulation model also accounts for 36% of the variation in the average plant size in the sample.

3.4 **Conclusion**

In this paper, I present a model of managerial skill complementarities to account for the plant size distribution in a distortion free economy. Then, I explore how differences in aggregate productivity and aggregate barriers to investments across countries affect plant size distribution and aggregate output. The model has three important results. First, the model can explain the plant size distribution in the U.S. economy including the upper tail which accounts for a significant share of employment and output. Second, I show that even aggregate barriers to investments can have non-trivial effects on the plant size distribution and output in an otherwise canonical Lucas (1979) span-of-control model. Finally, differences in relative price of investment along with differences in productivity across countries can account for a significant portion of the variation in the plant size distribution across countries.

The benchmark model calibrated to U.S. data has interesting implication for life-cycle evolution of managerial income in the U.S. Average managerial income in the model shows the following two properties: Average managerial income is higher for older cohorts and the growth rate is disproportionately higher for older cohorts. In particular, average income is about 1.5 times higher for managers between ages 30 and 40 than for managers between ages 20 and 30. Again, average income is 1.8 times higher for managers between ages 40 and 50 than for managers between ages 30 and 40. Finally, average managerial income is about 2.5 times higher for managers between ages 50 and 60 than for managers between ages 40 and 50. It would be interesting to see how the evolution of average managerial income compare with the data. I collect data on total compensation and age of 4369 CEOs from S&P's execucomp database for the year 2004. I find that average compensation for CEO's between the ages of 50 and 41 is about 2 times higher than the average compensation for CEO's between the ages of 40 and 31 However the average compensation for CEO's between the ages of 60 and 51 is only 1.3 times higher than the average compensation for CEO's between the ages of 50 and 41. Although this is informative, a direct comparison of the data with my model statistic is not possible because of the following two limitations: Firstly, the data is collected on firms and a firm could be defined by more than one plant. Hence, the definition of an economic unit in the data could be different from the definition in the model. Secondly, the average firm size in the data is 40 which is significantly higher than the average plant size in the model. In fact these differences might partly explain why the growth rate of managerial income is higher in the model than in the data.

APPENDIX A

TABLES

Table A1: Parameters

Parameter	Description	Value
$\alpha\gamma$	Capital share in Output	0.326
g	Population Growth	0.011
δ	Depreciation rate	0.04

Table A2: Calibrated Parameters

Parameter	Description	My Model	Exogenous-Skill Model
α	Importance of Capital	.415	.468
β	Discount Factor	.5248	.93
θ_1	Skill Technology 1	.9614	—
θ_2	Skill Technology 2	.389	—
σ	Variance Skill Distribution	2.2819	3.9326

Table A3: U.S. Data and Benchmark Model Targets

Statistic	U.S. Data	Exogenous Skill Model	My Model
Capital Output Ratio	.2325	.2325	.2325
Mean Size	17.864	17.87	17.603
Fraction of Small Plants	.725	.7158	.7159
Fraction of Large Plants	.0263	—	.0258
Employment Share in Large Plants	.4616	—	.4611

Table A4: Descriptive Statistics, Benchmark Model

Manager Cohort	1	2	3	4
Mean Ability	134.12	208.9	385.9	995.7
Mean Productivity	2.9	3.1	3.4	3.8
Output per Manager	8.5	13.3	24.6	63.4
Plants	All Plants	Small Plants	Large Plants	
Mean Size	17.7	4.42	315.66	
Number of Plants		71.6%	2.6%	
Employment Share		17.9%	46%	
Output per Plant	25.09	6.3	448.23	

Table A5: Cross Country Data on Aggregate Statistics and Plant Size

Country	Output per Worker	P_I	Mean Size	Percentage of Plants		Employment Share (%)	
				Small	Large	Small	Large
Bangladesh (BAN)	4581.53	2.74	3.2	97.3	0.12	70.7	13.6
India (IND)	8035.81	1.94	4.4	95.8	0.34	60	19
Japan (JPN)	56141.31	0.98	9.1	80.8	0.90	28.3	24.9
Jordan (JOR)	17173.36	2.10	4.3	98.1	0.32	55.1	30.3
Lithuania (LTU)	24561.09	1.82	14.2	78	1.49	17.0	40.7
Norway (NOR)	85284.36	1.03	15	74	2	19	33.0
Pakistan (PAK)	9628.69	1.90	4	97.6	0.15	71.3	14.1
Spain (SPA)	59527.76	1.28	9	88	0.73	27	39.7
Taiwan (TAI)	19885.65	1.42	6.6	89	0.60	27.7	31.5
Uganda (UGA)	2670.82	7.17	10.7	75.2	1.34	35.9	12.5
United Kingdom (UK)	60875.73	1.03	11.8	80.7	1.70	15	41.4
United States (US)	80691.52	1	17.9	72.5	2.63	15.1	46.2
Vietnam (VIT)	5812.99	2.50	3.7	95.6	0.30	43.5	28.7

P_I: Relative Price of Investment.
Source: 2004 Penn World Tables and Official Country Census Data.
See Appendix D for details.

Table A6: Effects of a Tax on Capital Rental

Statistic	Benchmark Model	100% Rental Tax		150% Rental Tax	
		Closed Economy	Open Economy	Closed Economy	Open Economy
Aggregate Output	100	74.78	67.2	67.3	59.3
Capital Output Ratio	100	58.3	50	48.3	40
Output per plant	100	69.8	59.6	61.2	50.8
Mean Manager Productivity	100	97.6	95.7	96.7	94.5
Mean Manager Quality	100	86	75	80.8	69
Workers (%)	94.6	94.2	93.9	94.07	93.7
Mean Size	17.6	16.3	15.48	15.9	14.9
Number of					
Large Plants	100	92.2	86.4	89.1	82.6
Small Plants	100	101.2	101.4	101.5	101.8
Employment Share					
Large Plants	100	93	86	90	81.5
Small Plants	100	107.68	114.4	111	119

Table A7: Effects of an Aggregate Technology Barrier

Statistic	Benchmark A=1	A=0.5		A=0.25	
		Closed Economy	Open Economy	Closed Economy	Open Economy
Aggregate Output	100	31.7	30.4	10.6	9.9
Capital Output Ratio	100	106.9	100	112.5	100
Workers (%)	94.6	92.8	92.7	91.48	91.36
Mean Size	17.6	12.84	12.63	10.7	10.6
Number of					
Large Plants	100	65.5	63.6	42.2	39.9
Small Plants	100	103.4	103.5	105.4	105.5
Employment Share					
Large Plants	100	62.4	60	36.2	33.6
Small Plants	100	138.8	141.2	166.6	169.3

Table A8: Effects of 75 pct fall in the Plant Technology Parameter

Statistic	Manager Cohort		
	All	Youngest	Oldest
Output per plant			
Closed Economy	-93.3%	-85.5%	-96.2%
Open Economy	-93.8%	-86.2%	-96.6%
Average Manager Ability			
Closed Economy	-69.3%	-28.7%	-82%
Open Economy	-68.2%	-29.4%	-82.7%
Average Manager Productivity			
Closed Economy	-15.9%	-8.7%	-25%
Open Economy	-16.4%	-9%	-25.2%

Table A9: Differences in Plant Size between U.S. and India explained by the model

Size Class	U.S. (Benchmark)	India Model	India Data	% Model
		Employment Share		
<11 (Small)	17.3%	28.7%	60.3%	26.5%
>99 (Large)	46%	16.9%	18.9%	92.6%
		Number of Plants		
<11 (Small)	71.5%	75%	95.8%	14.4%
>99 (Large)	2.6%	1.1%	.03%	58.4%

Table A10: Fraction of Managers Operating Large Plants in India and U.S.

Manager Cohort (by age)	Benchmark Model (U.S.)	India A=.28, rental tax=93.8%
20-30	0%	.11%
30-40	0.34%	.51%
40-50	3.36%	0.99%
50-60	8.09%	1.53%

Table A11: Fraction of Managers Operating Small Plants in India and U.S.

Manager Cohort (by age)	Benchmark Model (U.S.)	India A=.28, rental tax=93.8%
20-30	83.9%	83.56%
30-40	75.79%	76.1%
40-50	66.19%	67.42%
50-60	55.28%	57.67

Table A12: Cross Country Variation in Plant Size Explained by the Model

Statistic	Data	Model	% Model
	Coeff. of Variation		
Small Plants	0.098	0.021	21.43
Large Plants	0.83	0.42	50.6
Employment Share in Small Plants	0.5	0.2	40
Employment Share in Large Plants	0.43	0.5	116
Mean Plant Size	0.55	0.2	36.4

APPENDIX B

FIGURES

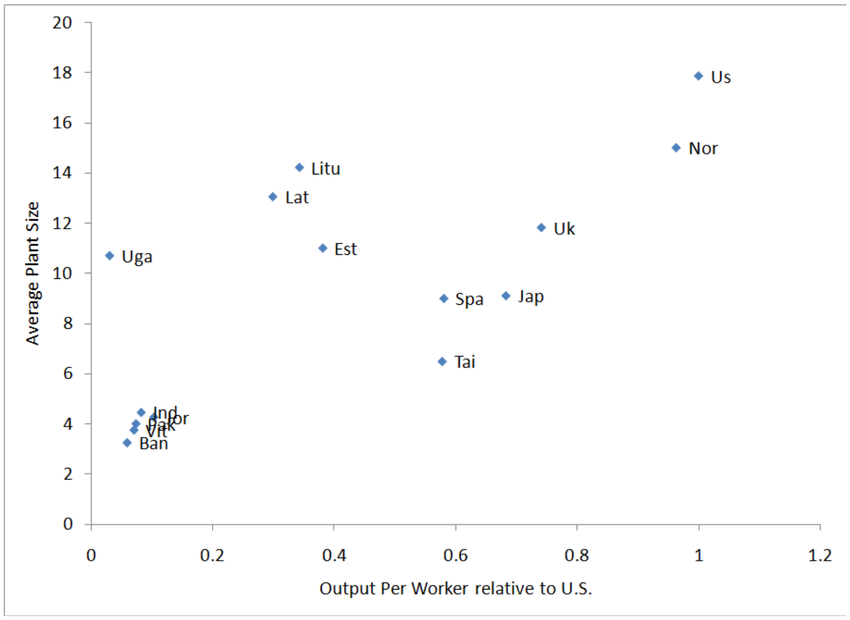

Figure B1: Output per Worker versus Average Plant Size

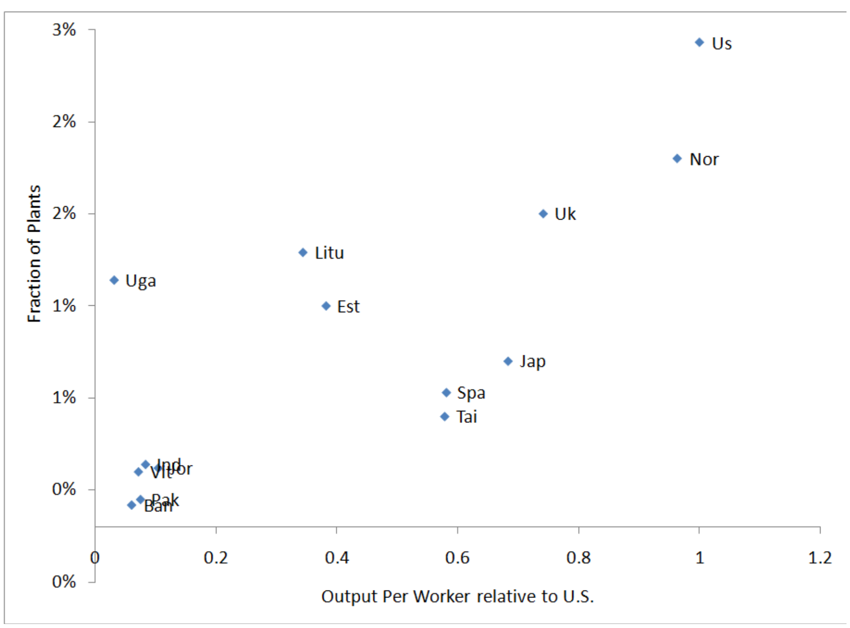

Figure B2: Output per Worker versus Plants with at least 100 employees

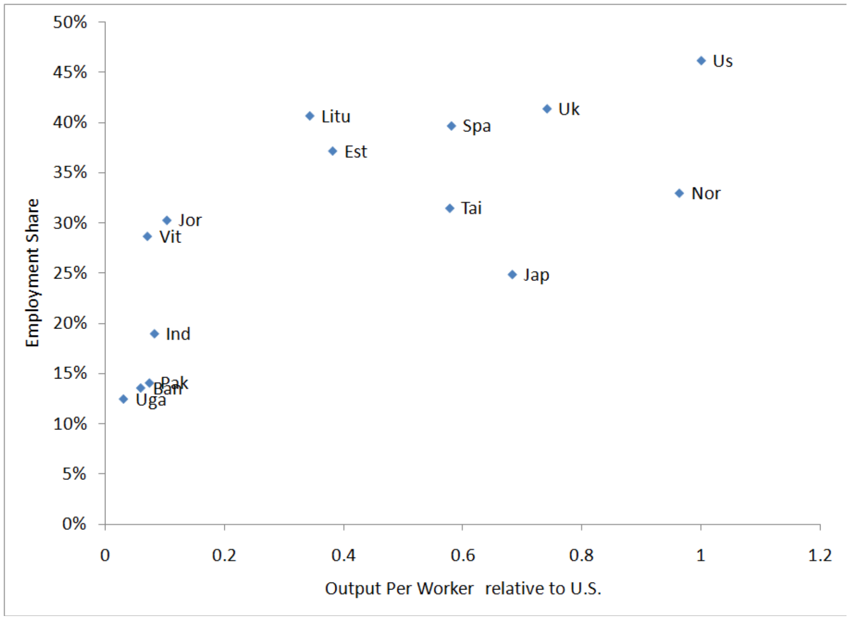

Figure B3: Output per Worker versus Employment in Plants with at least 100 Employees

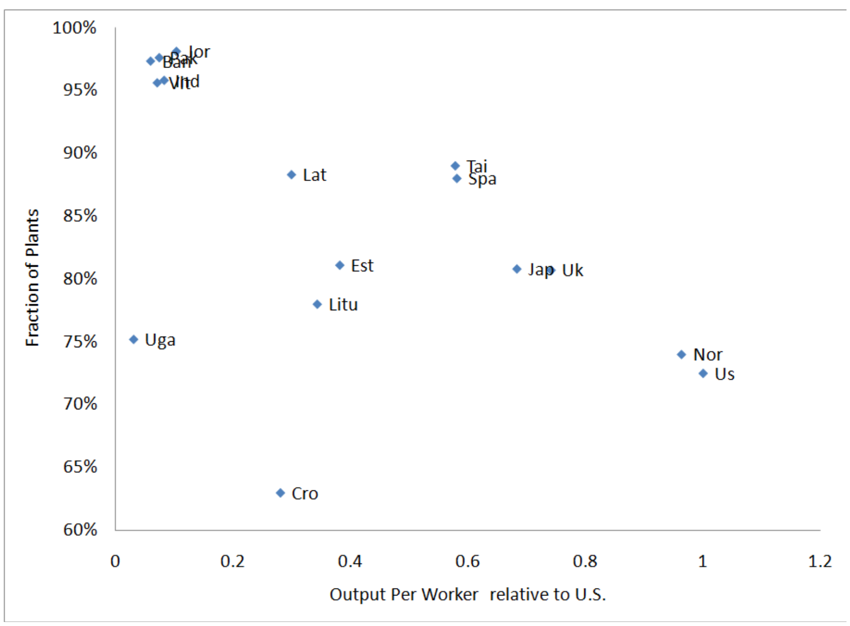

Figure B4: Output per Worker versus Plants with at most 10 employees

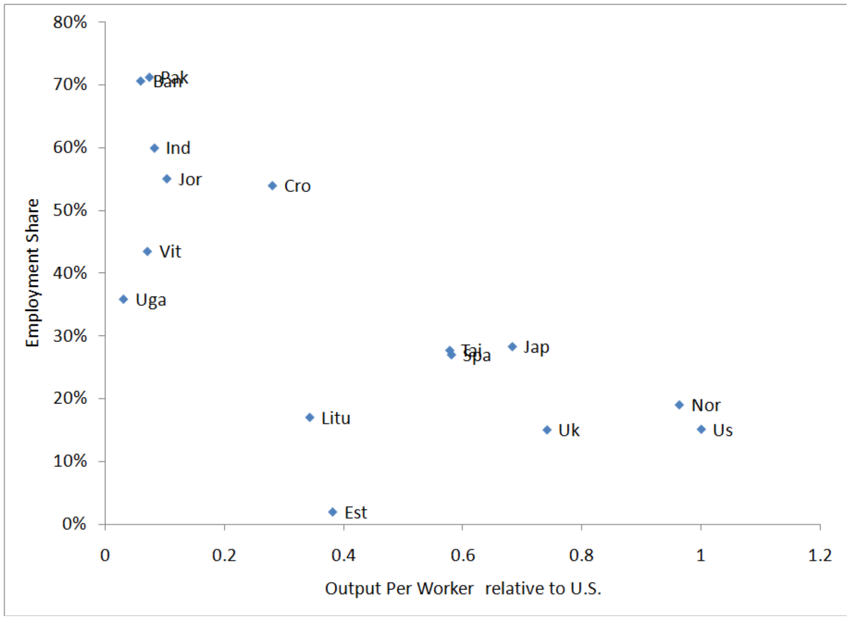

Figure B5: Output per Worker versus Employment in Plants with at most 10 Employees

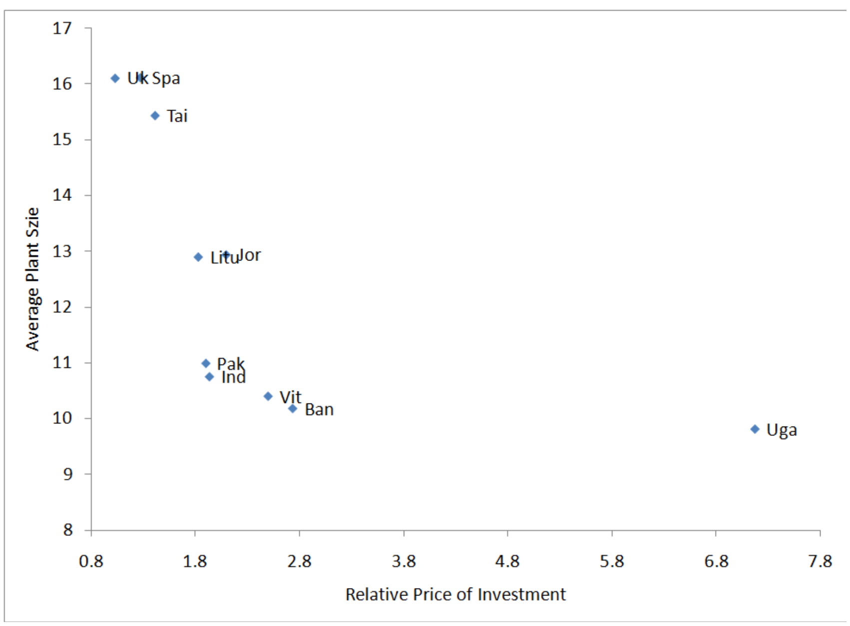

Figure B6: Relative Price of Investment versus Average Plant Size

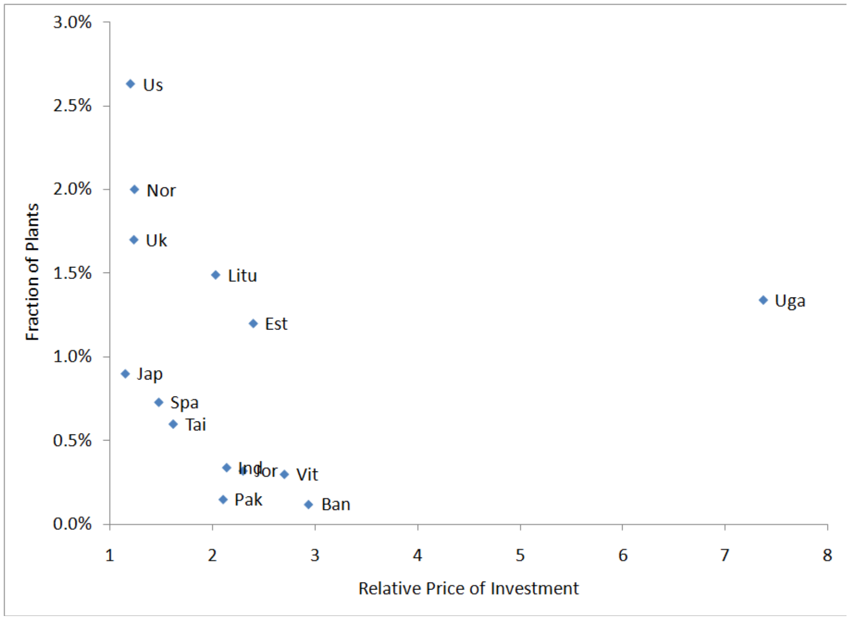

Figure B7: Relative Price of Investment versus Plants with at least 100 Employees

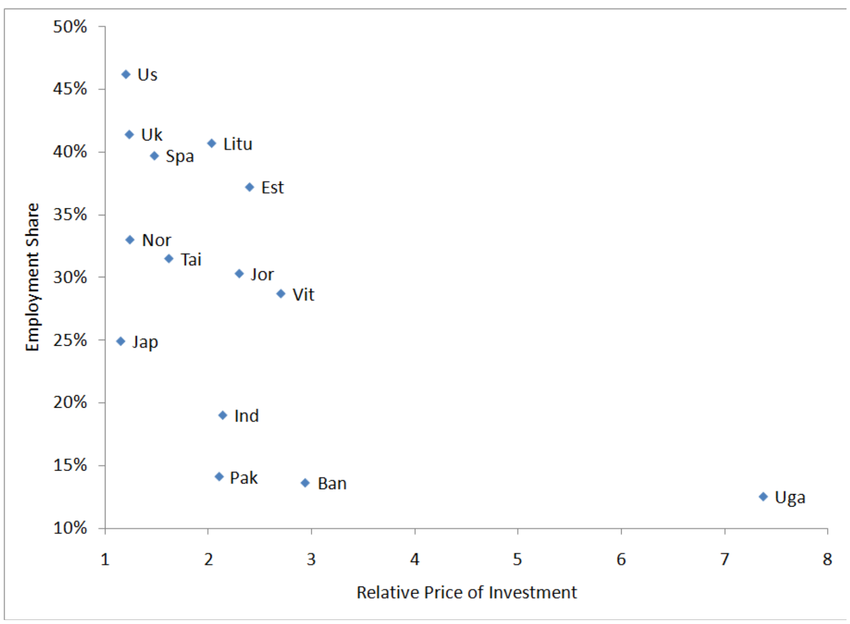

Figure B8: Relative Price of Investment versus Employment in Plants with at least 100 Employees

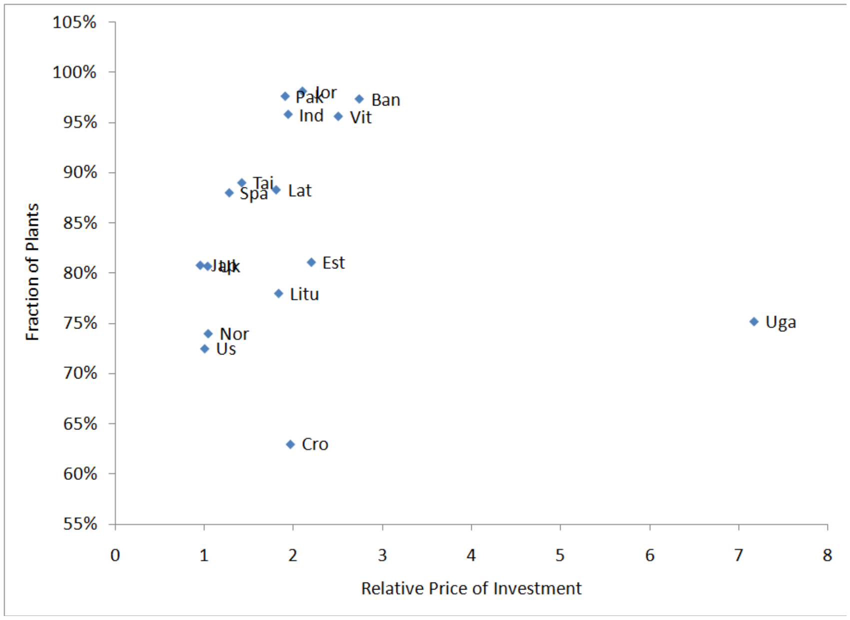

Figure B9: Relative Price of Investment versus Plants with at most 10 Employees

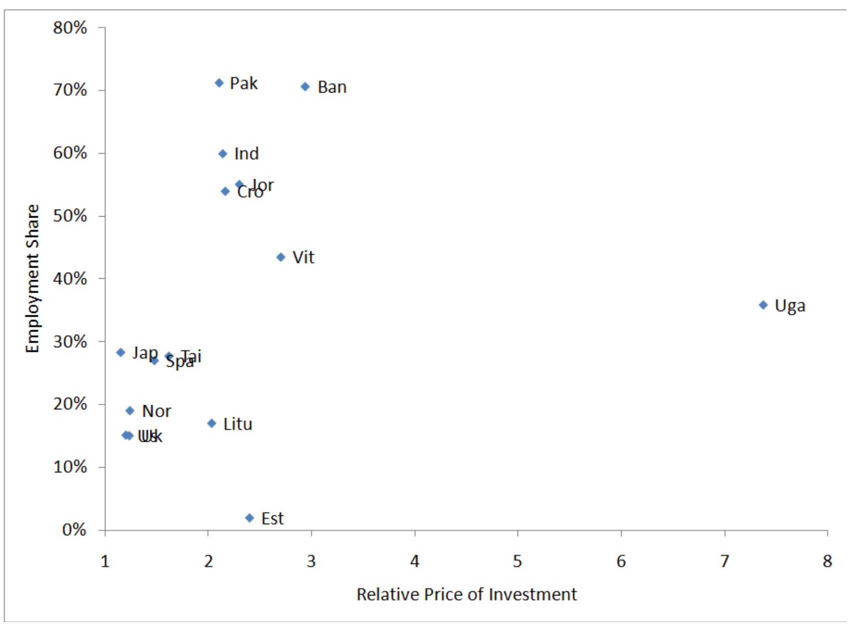

Figure B10: Relative Price of Investment versus Employment in Plants with at most 10 Employees

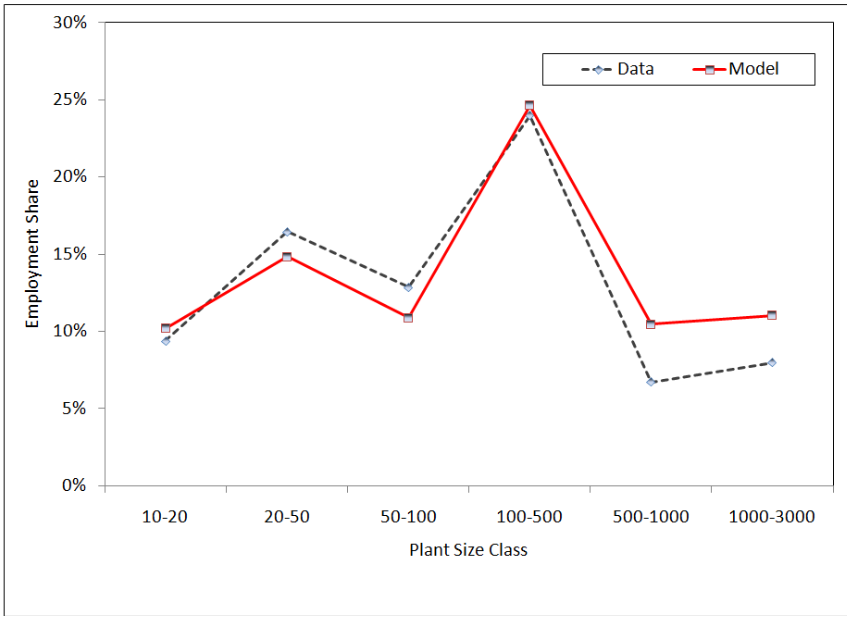

Figure B11: Employment Share by Plant Size Class, U.S. Data and Benchmark Model

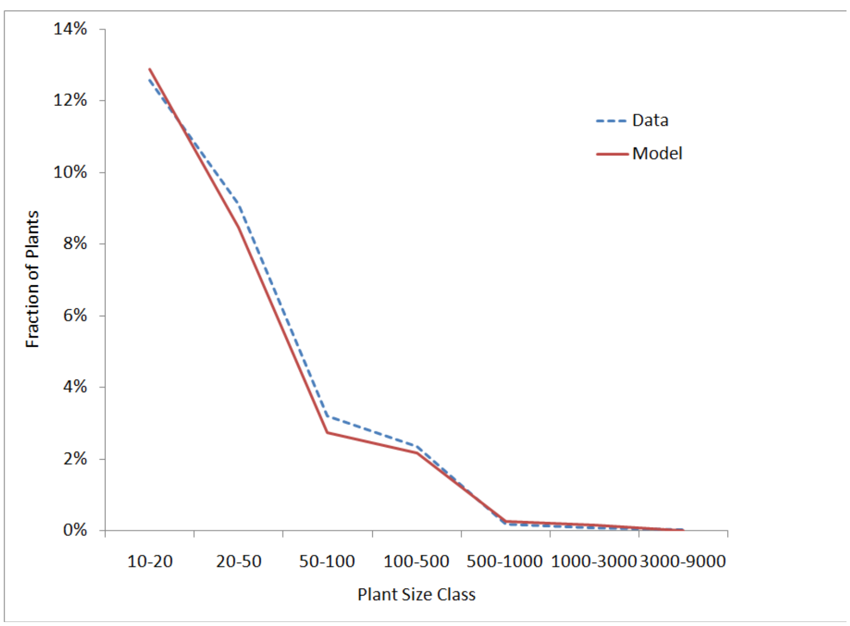

Figure B12: Plant Size Distribution, U.S. Data and Benchmark Model

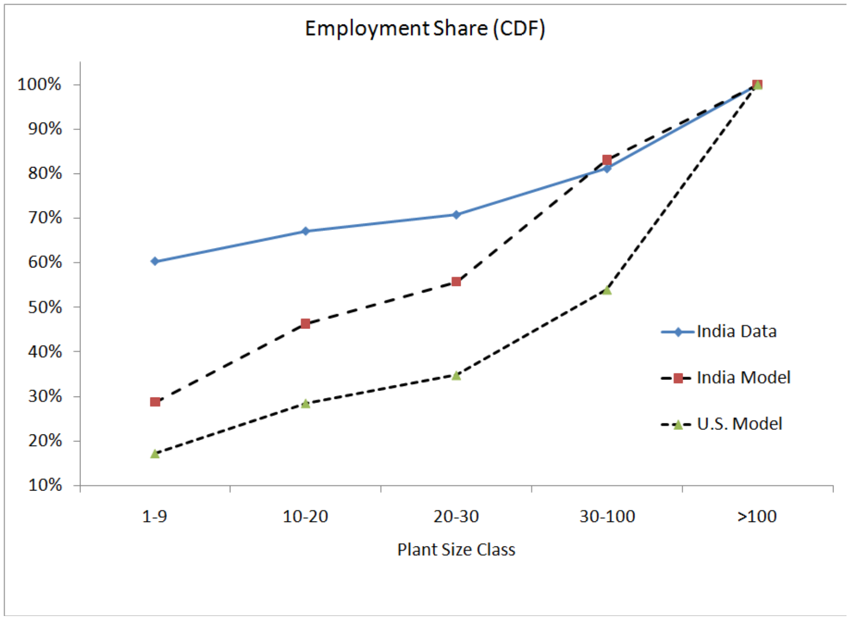

Figure B13: Difference in the Employment Share distribution between India and U.S. explained by the Model

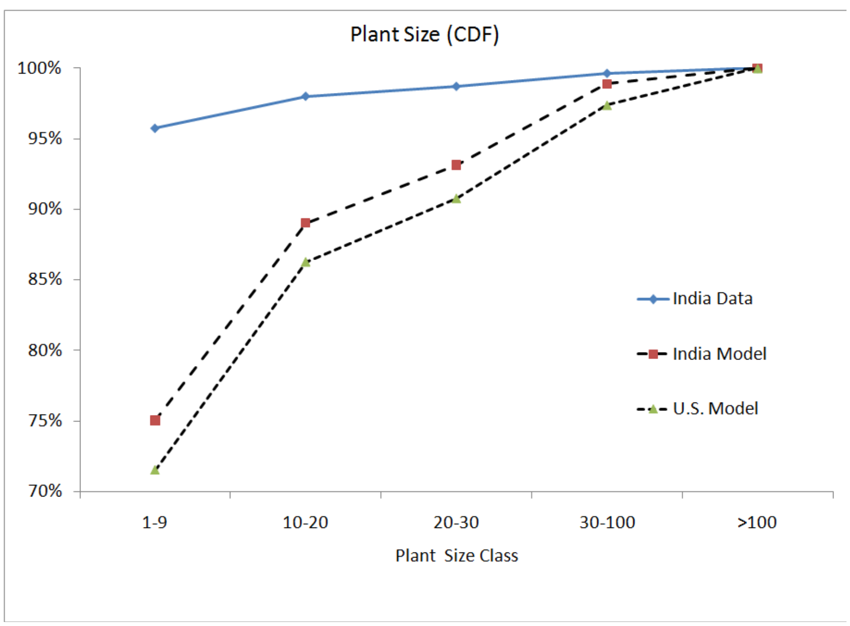

Figure B14: Difference in the Plant Size distribution between India and U.S. explained by the Model

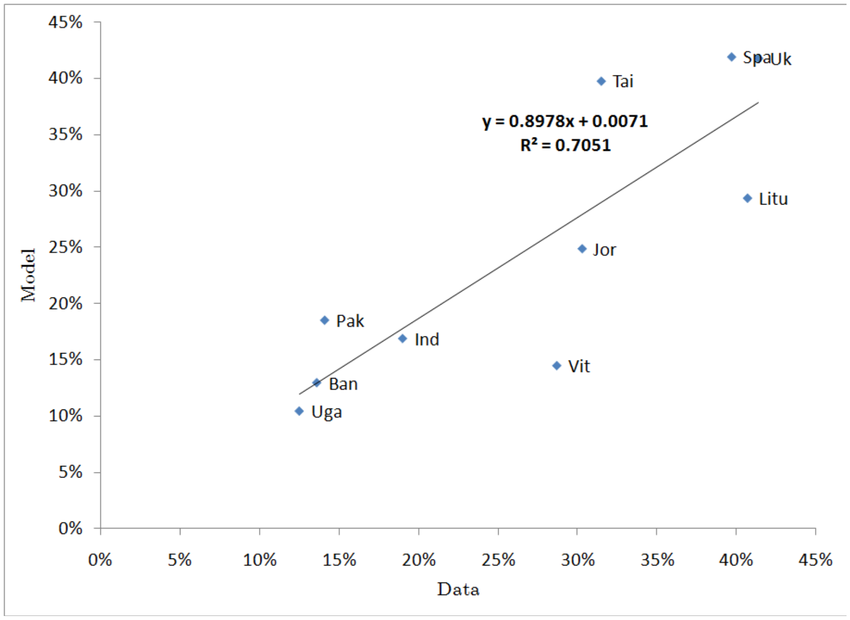

Figure 15: Share of Employment Accounted for by Plants with at least 100 Employees, Data versus Model

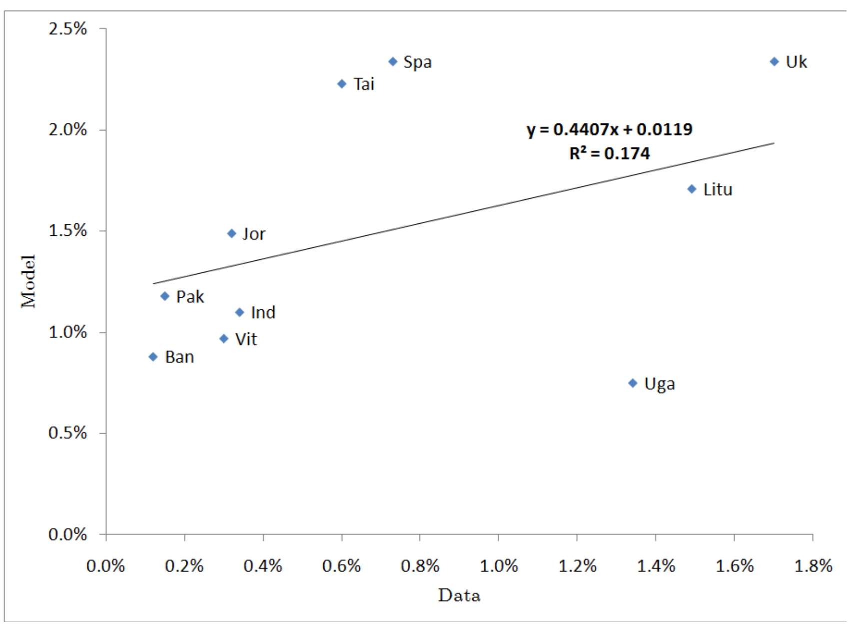

Figure B16: Fraction of Plants with at least 100 Employees, Data versus Model

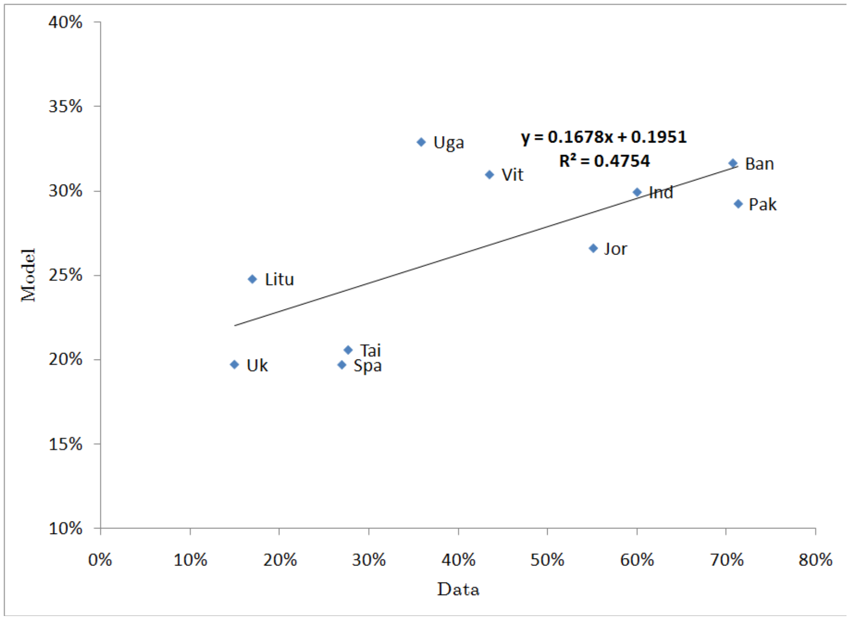

Figure B17: Share of Employment Accounted for by Plants with at most 10 Employees, Data versus Model

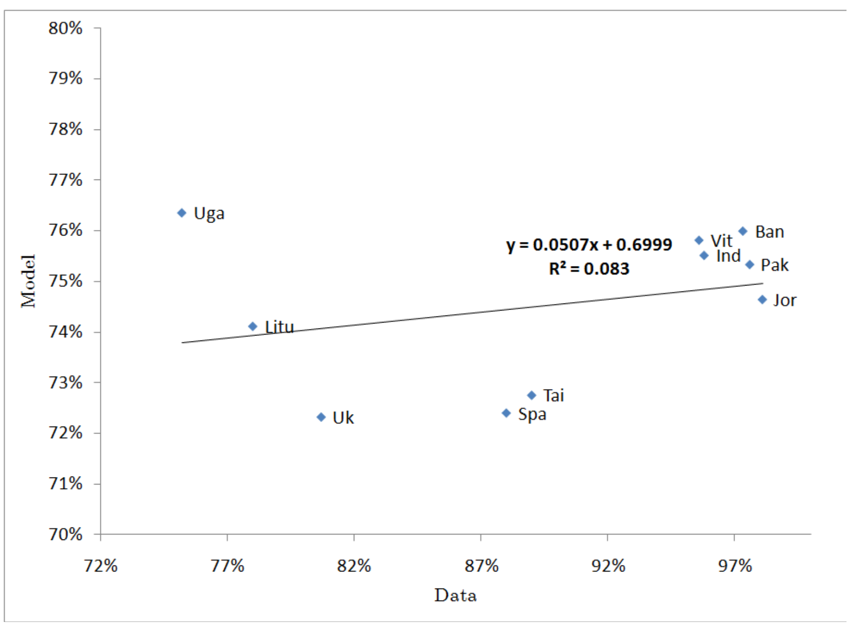

Figure B18: Fraction of Plants with at most 10 Employees, Data versus Model

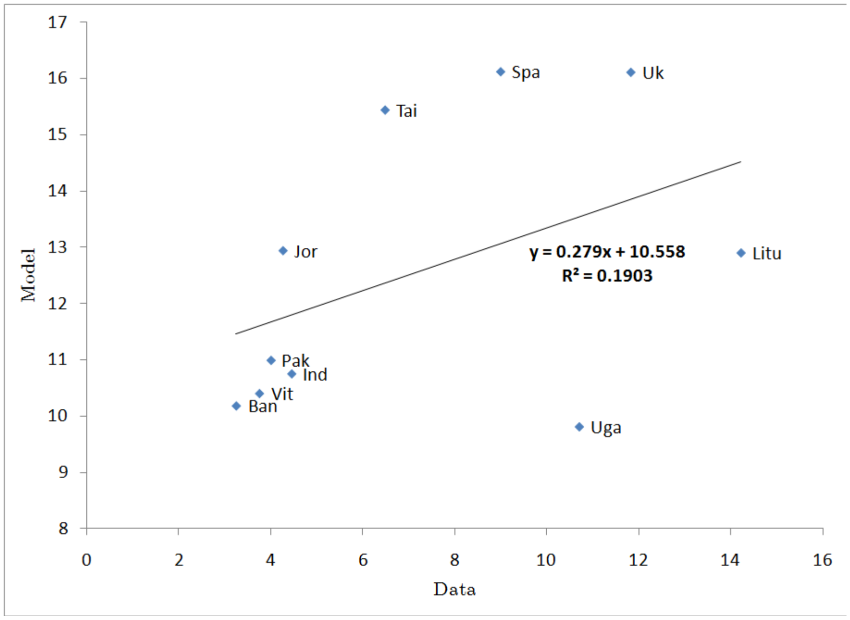

Figure B19: Average Plant Size, Data versus Model

APPENDIX C

AGGREGATE BARRIERS IN AN EXOGENOUS SKILL MODEL

In this section I will show that aggregate barriers have no effect on the plant size distribution in an exogenous skill model. Consider a two period version of the model in steady state with a perfectly elastic capital market and no population growth. Consider the following type of aggregate barrier: A proportional tax on the rental price of capital. Firstly, I will show that in the new steady state, the proportion of managers and workers does not depend on the capital rental tax. Secondly, for every manager, that optimal pre tax demand for labor is equal to the optimal post tax demand for labor. Thirdly, aggregate demand for labor remains unchanged after the tax.

Substituting the value of labor demand from equation 17 into equation 7 I get

$$2\left(\frac{1}{1+t}\right)^{\frac{\alpha\gamma}{1-\gamma}} c\left(\frac{1}{w_a}\right)^{\frac{1-\alpha\gamma}{1-\gamma}} \int_{\widehat{z}_a}^{\overline{z}} z dF(z) = 2F(\widehat{z}_a) \tag{C1}$$

where, $\widehat{z}_a$ denotes the managerial ability of the marginal manager in the model with an aggregate barrier, w_a denotes the steady state wage rate in the model with an aggregate barrier, $c = (1-\gamma)A^{\frac{1}{1-\gamma}}\left((1-\alpha)\gamma\right)^{\frac{1}{1-\gamma}}\left(\frac{\alpha}{1-\alpha}\right)^{\frac{\alpha\gamma}{1-\gamma}}\left(\frac{1}{r+\delta}\right)$, and $F(z)$ is an exogenous distribution of intrinsic managerial ability with $z \in [\underline{z}, \overline{z}]$. C1 implies that

$$\left(\frac{1}{1+t}\right)^{\frac{\alpha\gamma}{1-\gamma}} c\left(\frac{1}{w_a}\right)^{\frac{1-\alpha\gamma}{1-\gamma}} E(z|\widehat{z}_a) = F(\widehat{z}_a) \tag{C2}$$

Again, for the marginal manager, $V^m(\widehat{z}_a) = V_a^w$. This implies that $\pi_a = w_a$. Substituting the value of π_a from equation 18 I get,

$$d\left(\frac{1}{1+t}\right)^{\frac{\alpha\gamma}{1-\gamma}}\left(\frac{1}{w_a}\right)^{\frac{\gamma(1-\alpha)}{1-\gamma}} \widehat{z}_a = w_a \tag{C3}$$

where, $d = A^{\frac{1}{1-\gamma}}(1-\gamma)\left((1-\alpha)\gamma\right)^{\frac{\gamma}{1-\gamma}}\left(\frac{\alpha}{1-\alpha}\right)^{\frac{\alpha\gamma}{1-\gamma}}\left(\frac{1}{r+\delta}\right)^{\frac{\alpha\gamma}{1-\gamma}}$

Substituting the value of $\left(\frac{1}{w_a}\right)^{\frac{1-\alpha\gamma}{1-\gamma}}$ from C1 into C3 I get,

$$\frac{\widehat{z}_a F(\widehat{z}_a)}{E(z|\widehat{z}_a)} = \frac{c}{d}$$

$$\Rightarrow \frac{\widehat{z}_a F(\widehat{z}_a)}{E(z|\widehat{z}_a)} = (1-\alpha)\gamma\left(\frac{1}{r+\delta}\right)^{\frac{1-\gamma(1-\alpha)}{1-\gamma}} \tag{C4}$$

The above equation implies that in the new post tax steady state, $\widehat{z}_a$ is not a function of the capital rental tax. This also implies that in new steady state, the division of the workforce between workers and managers remain unchanged. Equation $C4$ also impies that

$$\widehat{z}_a = \widehat{z}_b = \widehat{z} \tag{C5}$$

where $\widehat{z}_b$ denotes the managerial ability of the marginal manager in the benchmark model. For the marginal manager,

$$\begin{aligned}
V^m(\widehat{z}_j) &= V_j^w, j = a, b \\
&\Rightarrow \pi(\widehat{z}_j) = w_j, j = a, b \\
&\Rightarrow \frac{\pi(\widehat{z}_a)}{w_a} = \frac{\pi(\widehat{z}_b)}{w_b} \\
&\Rightarrow w_a^{\frac{1-\alpha\gamma}{1-\gamma}} = (1+t)^{\frac{\alpha\gamma}{1-\gamma}} w_b^{\frac{1-\alpha\gamma}{1-\gamma}}
\end{aligned}$$

Substituting the value of w_b into equation 17it is easy to show that the optimal demand for labor does not change as a result of an aggregate barrier.

APPENDIX D

PLANT SIZE DATA

Bangladesh
Homepage: http://www.bbs.gov.bd/index.php
Direct Link: http://www.bbs.gov.bd/index5.php?category=40

India
Homepage: http://mospi.nic.in/Mospi_New/site/home.aspx
Direct Link: http://www.mospi.nic.in/index_6june08.htm

Japan
Homepage: www.stat.go.jp/english

Lithuania
Homepage: http://db1.stat.gov.lt/statbank/SelectTable/Omrade0.asp?PLanguage=1
Direct Link: http://db1.stat.gov.lt/statbank/SelectVarVal/Define.asp?Maintable=M4010118&PLanguage=1

Norway
Homepage: http://www.ssb.no/english/
Direct Link: http://www.ssb.no/bedrifter_en/arkiv/tab-2004-01-23-01-en.html

Pakistan
Homepage: http://www.statpak.gov.pk/depts/index.html
Direct Link: http://www.statpak.gov.pk/depts/fbs/publications/ec_2005/ch2.pdf

Spain
Homepage: http://www.ine.es/en/welcome_en.htm
Direct Link: http://www.ine.es/jaxiBD/menu.do?type=db&divi=dir&his=0&L=1

Taiwan
Homepage: http://eng.stat.gov.tw/mp.asp?mp=5
Direct Link 1: http://win.dgbas.gov.tw/dgbas04/bc2/ics95/GENERAL/EN/ZG51.pdf
Direct Link 2: http://win.dgbas.gov.tw/dgbas04/bc2/ics95/GENERAL/EN/ZG9.pdf

Uganda
Home Page: http://www.ubos.org/index.php
Direct Link: http://www.ubos.org/index.php?st=pagerelations&id=17&p=related%20pages:Business%20and%20Industry%20Statistics

United Kingdom
Home Page: http://www.statistics.gov.uk/default.asp
Direct Link: http://www.statistics.gov.uk/downloads/theme_commerce/PA1003_2004/PA1003_2004.pdf

United States
Home Page: http://www.census.gov/
Direct Link: http://www.census.gov/epcd/www/smallbus.html

Vietnam
Home Page: http://www.gso.gov.vn/default_en.aspx?tabid=491
Direct Link: http://www.gso.gov.vn/default_en.aspx?tabid=481&idmid=4&ItemID=1847

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