Technological Change and the Income Distribution: Theory and Some Evidence

Tianxi Wang and Greg C. Wright

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Abstract: This paper considers two types of technological change in a unified model. Type A is unskilled-biased, and yet raises income inequality. Type B increases the scale of operation for an occupation, allowing its practitioners to cheaply produce more. This hurts the least talented practitioners while it may benefit the most talented ones. Together, these technological changes may have contributed to the continuous rise in income inequality that developed economies have witnessed in recent decades. The paper compares the theoretical results with U.S. data and finds support for the predictions.

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[1]Tianxi Wang: Department of Economics, University of Essex. Email: wangt@essex.ac.uk. Tel: +44 (0)1206873480. Greg Wright: Department of Economics, University of California, Merced. Email: gwright4@ucmerced.edu.

1. Introduction

This paper considers the impact of technological change on the income distribution. Most commonly, technological change is modeled as a change in the productivity of production factors, usually denoted by the parameter A. In this paper we depart from this convention by distinguishing between two types of technological progress. One is type A, which increases the productivity of labor – an example of which is the invention of steam-driven coal-digging machines. The other is type B, which increases the reach or "scale of operation" (see Neal and Rosen (2000)) in some occupations – for example, the invention of the radio which transmits a singer's voice far beyond the walls of a theater. This paper considers the effects of both types of technological change in a unified model. We find, among other results, that an increase in A, though biased toward unskilled workers, raises income inequality, while also increasing the overall level of income in the economy. On the other hand, a type B technological progress likely benefits only the upper end of the income distribution within the affected occupations, while it always hurts those at the lower end. It has a further, ambiguous effect on all other occupations. The importance, and novelty, in considering type B technological change is that technological progress is often described as a force which "increases the size of the pie", with attention then drawn to who receives what portion of the additional income. However, the type B progress described here is different. Although it may allow goods or services to be produced more cheaply, its primary effects on the income distribution are through competition and workforce reallocation, as we will show. Having done so, we then exploit U.S. income and employment data in order to present some empirical findings that are consistent with the predictions of the model.

Two observations are key to this paper's modeling of type B technological change. First, apart from income generated from capital, people earn a living by supplying a production factor, which is either labor or human capital, and those occupations that require substantial human capital are subject to *Increasing Returns to Scale up to some Limit* (IRStL). Second, for a subset of these occupations the limit up to which IRS operates has increased significantly due to innovations in Information and Communication Technology (ICT), whereas in others it has not. Let us elaborate.

As a starting point we note that, as a rule, IRStL is present in occupations that demand substantial human capital or knowledge. Consider, as one example, childcare. A childcare worker may be able to take care of up to five children without lowering the quality of her service much, whereas below this number adding one more child does not add much additional cost, at least in terms of thel time required. As another example, a ship captain does not need to work much harder if her cargo ship is fully loaded than she does if it is empty. Her service therefore displays IRS up to the capacity of the ship. As a final example, it costs a lot to create a musical performance, but costs very little to admit an additional person into a theater to hear it, up until the point at which the theater is filled.

Innovation has clearly extended the range within which IRS operate for many occupations over the past century, with the ICT revolution of the past three decades doing so disproportionately for a particular subset of occupations, while having little effect on many others. Consider the examples above. The IRS limit for childcare workers has likely not changed at all. On the other hand, with ship capacity always growing the IRS limit for ship captains has continuously expanded. However, this change was minor compared to the effect of new technologies, such as radio and TV, on the limit of IRS for musicians whose products can thereby reach people far way from the walls of any theaters. Most recently, this limit soars again with the invention of the Internet, whereby potential buyers are now able to actively search vast databases of music (rather than passively receiving music news) and, in many cases, sample a portion of the music before purchase.

Our model incorporates these observations. In the model, we consider a continuum of agents with equal endowments of labor but heterogeneous endowments of human capital. They choose to subsist either by employing their labor, or by employing their human capital, thereby becoming a professional – for instance a singer – for which the quality of their output depends on the size of their human capital endowment.[1] Professionals hire unskilled labor in order to produce a stream of services. Unskilled labor is also used to produce a subsistence good. Unskilled labor is highly substitutable and therefore competes under perfect competition, but the services provided by individual professionals are differentiated – for instance, Madonna versus Jay-Z – and as a result, the market for these services is monopolistically competitive. To capture the observation that most occupations that demand substantial human capital display IRStL, the paper assumes that after committing his time to supply human capital (rather than labor) – the opportunity cost of his time is then a fixed cost – a professional hires labor to produce his variety of services at constant returns to scale up to scale B. This B represents the scale of operation for a professional; for example, the capacity of the theater in which a musician performs, the capacity of a ship that a captain operates, or the number of children a childcare worker can attend to without compromising the quality of her services. The productivity of unskilled labor is A. The focus of the paper, then, is to examine the implications of a rise in the IRS limit (i.e., an increase in B) or an increase in the productivity of unskilled labor (i.e., an increase in A) for the income distribution.

Consider an increase in B. On the one hand, each professional is able to produce more, which benefits them. On the other hand, since the production capacity of all professionals increases, each of them faces fiercer competition. While this increase in competitive pressure is the same for all professionals, the expansion in output capacity delivers greater benefits to those who have

[1] This feature of an identical labor endowment and heterogeneous human capital (or ability) is also found in Lucas Jr (1978) and Monte (2011).

more human capital and are therefore able to charge a higher price for their stream of services. This results in two outcomes. (a) Income inequality between professionals increases: there exists a critical level of human capital such that the professionals with human capital beyond this point realize net gains from the increase in B, while those below it lose. (b) Another, lower threshold of human capital exists such that practitioners below this point are squeezed out of the profession into providing unskilled labor.

Next consider an increase in A, the productivity of unskilled labor. This increases the real income of those who choose to provide unskilled labor. But it increases the income of those who choose to become professionals even more, and the higher their human capital, the greater the rise in income. This is generated by two economic forces. First is the choice of occupation: we show that (c) an increase in A drives agents out of providing unskilled labor into professional work. Second is a general equilibrium effect: with all workers getting richer, spending becomes increasingly skewed toward higher quality goods produced with high human capital. As a result, an increase in A (d) increases income inequality, while (e) also increasing the income level of all workers.

We extend our model to consider the impact that an increase in the IRS limit in one occupation has on another occupation for which the limit of IRS is unchanged (which we refer to as an "unaffected" occupation). We show that (f) an increase in the IRS limit in the affected occupation may also reduce the income of *all* the practitioners in the unaffected occupation.

We bring these ideas to U.S. data by exploiting the natural experiment generated by the rapid expansion of Internet access beginning in the late 1990s. Specifically, we ask whether the pattern of wage and employment trends in the Internet period diverged from the pre-Internet period to a significant degree and in a manner consistent with the predictions of our model. In doing so, we test the hypothesis that the rapid expansion of Internet access extended the IRS limit for a subset of occupations. At the same time, we assume that type A technological change is effectively constant due to the fact that average labor productivity growth across these periods was approximately equal (2.2 percent for the pre-period and 2.3 percent for the post-period). In light of this, our empirical exercise focuses on two groups of occupations: those whose IRS limit was potentially increased by the Internet and those that were likely unaffected. Formally, we apply a difference-in-differences strategy, comparing the within-occupation inequality across the two occupation types over the pre- and post-Internet periods, an approach that effectively removes the common trend due to type A technological progress (and any other trends common to the groups).

Noting that our analysis should be interpreted as suggestive rather than definitive, consistent with prediction (a) we find that Internet-affected occupations saw widening inequality during the Internet period that included wage losses for lower-end workers. This was in contrast to the pre-Internet period as well as in comparison to the group of occupations unaffected by the Internet and to the overall economy-wide trend. We also test the model's predictions with respect to patterns of employment, given by results (b) and (c) above. Taken together, these results predict that relative to unaffected occupations, the employment in affected occupations will fall due to the effects of the Internet. We find evidence in favor of this prediction.

The paper proceeds as follows. Section 2 places our paper within the existing literature. Sections 3 and 4 present our theory of technological change. Section 5 brings some predictions of the model to the data. Section 6 provides some concluding remarks.

2. The Literature

A major theme of our paper, that technological development affects the income distribution, fits within a very large strand of literature that approaches the topic from a variety of perspectives.[2] Relative to this literature, our main innovations are twofold. First, we classify technological change as belonging to one of two categories – category A (namely those advances that increase the productivity of factors) and category B (those that promote workers' reach and scale of operation) – and we model these technological changes in a unified framework.

Second, we introduce new mechanisms through which technological changes can affect the income distribution. In this sense, the comparative statics of our model can be usefully compared with those from the dominant theory of Skill-Biased Technical Change (SBTC). For instance, we show that technological progress of type A, though biased toward unskilled labor, increases income inequality through workers' choice of occupation as well as via general equilibrium effects. As far as we know, this mechanism is new to the literature and the result directly contrasts with the implications of the SBTC literature in which unskilled-biased technologies should *decrease* inequality.[3] At the same time, type B technological progress leads to an increase in wage inequality that looks much like that predicted by SBTC models. However, in our model this effect is generated through competition and workforce reallocation and has little in common with the capital-skill complementarity that is at the heart of the SBTC mechanism. This also suggests that many of the stylized facts attributed to SBTC may, at least in part, be due to the mechanism we describe here.

Along these lines, in an important recent paper Guvenen and Kuruscu (2012) show that simply adding heterogeneity in the ability to accumulate human capital to a standard SBTC framework generates a set of predictions for wages that accurately mirrors features of the U.S. wage distribution

[2]As just a few representative examples: Autor, Levy and Murnane (2003) find that computers displace routine workplace tasks and complement cognitive-intensive, non-routine tasks; Firpo, Fortin and Lemieux (2012) adopt a novel decomposition approach and find an important role for technology in generating the observed inequality pattern over the 1980s, 1990s, and 2000s; Beaudry, Doms and Lewis (2010) find that computer adoption increases the return to skill; and Chen, Forster and Llena-Nozal (2013) find that technology has increased inequality across OECD countries.

[3]Canidio (2013) also presents a model in which unskilled-biased technological change can increase inequality. He models technology as factor-augmenting and considers its effect on steady state inequality. In the model, inequality arises from the interaction between investments in skill and borrowing constraints. This is quite different than the mechanism in our model, in which underlying heterogeneity in human capital determines the degree of inequality.

over the past four decades. We see this paper as complementary to ours, in the sense that both papers consider income inequality from the perspective of differentiation in agents' human capital endowments. However, as noted, we depart from the SBTC structure by differentiating between two forms of technological change, one of which, type B, augments skill (i.e., human capital) by increasing its scale of operation, rather than via a direct increase in its productivity. Moreover, the outcomes for skilled workers – i.e., the competition and workforce reallocation experienced by entertainers in our paper – are not always positive. A final difference between our paper and Guvenen and Kuruscu (2012) is that we focus on occupation choice, rather than accumulation of human capital, as the driving mechanism.

The mechanisms we describe are also novel in that they operate within occupations rather than across occupations, which is the focus of much of the literature. For example, the "job polarization" literature explores patterns in wage variation across different occupations but largely sets aside dynamics within occupations (see Acemoglu and Autor (2011)). However, there is empirical evidence that within-occupation variation is important. For instance, Autor et al. (2003) find that changes in the task content within occupations can explain half of the increase in the relative demand for college labor in the U.S. over the period 1960 to 1998. Similarly, Goos and Manning (2007) for the U.K. and Helpman, Itskhoki, Muendler and Redding (2012) for Brazil find that growth in inequality has occurred largely within occupations.

The role of "scale of operation" as it relates to the return to skill has long been noted in the literature in order to explain certain features of the income distribution. In particular, the earnings of "superstars" or CEOs have been the focus of, among others, Rosen (1981), Rosen (1983), Gabaix and Landier (2006), and Egger and Kreickemeier (2012) (see Neal and Rosen (2000) for a summary).[4] However, these papers are not mainly concerned with the effects of technological progress on the income distribution, nor do they differentiate between the two types of technological progress that we identify.[5]

Interestingly, the structure of our model has some of the flavor of Melitz (2003),[6] though the two papers are ultimately concerned with different issues.[7] In both papers IRS plays an important role,

[4]The scale of operation in Rosen (1981) is the size of the market that a superstar can capture; in Rosen (1983) it is the span of control to which managerial talents are applied; in Gabaix and Landier (2006) it is the size of the firms to which CEOs are assigned (following assignment models of Sattinger (1993) and Teulings (1995); and in Egger and Kreickemeier (2012) it is the number of workers, the productivity of whom all is increased by a more-able manager.

[5]Rosen (1981) provides an informal discussion regarding the effects of changes in external dis-economies of scale, which could be interpreted as an increase in B in our paper. However, he argues that a primary outcome would be "greater rents for all sellers", whereas in our paper an increase in B reduces the income of those whose human capital is below some threshold (see result (a) above).

[6]More accurately, our model is in line with Melitz (2003)-style models that incorporate heterogeneity in product quality, since the heterogeneity we introduce augments the marginal value of a unit of consumption, as in those models. For instance, see Baldwin and Harrigan (2007) or Kugler and Verhoogen (2012).

[7]Our paper is concerned with the income distribution (especially within-occupation inequality) in a closed economy, while Melitz (2003) is mainly focused on aggregate productivity in an open economy.

though in our paper it is IRS *up to some limit.* Furthermore, the insights from Melitz (2003) are quite different from those that arise in our setting. For instance, unlike Melitz (2003), in our model aggregate demand is not directly affected by an increase in B – the analog to market integration in Melitz (2003) – and may decrease with it due to a general-equilibrium effect. As another example, an extension of Melitz (2003) by Chaney (2008) shows that a reduction in variable trade costs induces entry by non-exporters into exporting, whereas in our model an increase in B drives agents out of the differentiated sector – i.e., the comparative statics with respect to the extensive margin are reversed.

There is other theoretical work that studies, from a different angle and in a different context, the effects of technological advancement on the income distribution. Garicano and Rossi-Hansberg (2004) and Saint-Paul (2007) examine the effects of reduced communication costs on the income distribution, where knowledge production and the organization of this production play an important role. Saint-Paul (2006) studies how productivity growth affects income inequality when consumers' utility from product variety is bounded from above.[8]

3. The Model

The economy is populated by a continuum of agents. Agent $i \in [0, 1]$ is endowed with one unit of labor and h_i units of human capital. Without loss of generality, let h_i be increasing in i, that is $h_i' := \frac{dh_i}{di} \geq 0$. Agents choose to live on their labor endowment or else on their human capital.[9] In the latter case, they provide a stream of services which, to fix ideas, we assume throughout to be entertainment services. The quality of the services provided by an agent depends on the size of his human capital and, for simplicity, is assumed to be equal to it.

Labor is used for producing both a subsistence good (such as food) and entertainment services. The production of the subsistence good is subject to perfect competition and displays constant returns to scale. If L agents are employed to produce it, then the aggregate output of the subsistence good is

$$Y = AL.$$

Within the entertainment occupation, entertainment services provided by different agents are each unique in some dimensions (for instance, consider the difference between Jay-Z and Madonna)

[8] More generally, the forces influencing the income distribution of an economy are clearly numerous and interrelated, and technological progress constitutes but one potential influence. Beyond the effects of technology, the economics literature has explored many other factors, such as globalization, demographic changes, labor rents, unions, and the minimum wage, to name just a few (see Katz and Autor (1999) for a survey of this literature).

[9] Of course, in reality nearly all occupations require both labor and human capital. But clearly some occupations demand more of human capital than labor (e.g. academics), while others demand more of labor than human capital. This paper, for simplicity, abstracts this continuum of human capital-to-labor combination into a binary choice.

and thus compete under monopolistic competition. As a result, each entertainer provides a unique variety of entertainment services, indexed by his identity $i \in [0,1]$. To produce his entertainment services, an agent needs to hire labor. The agent, having committed his time to supply human capita rather than labor, can hire labor to produce output at constant returns to scale up to the limit B. If the wage for labor is given by w, then the associated cost function is

$$C(y) = \left\{ \begin{array}{c} F + w\frac{c}{A}y, \text{ if } y \leq B \\ \infty, \text{ if } y > B. \end{array} \right\}, \tag{1}$$

where F is the opportunity cost of the agent's time. Since the alternative usage of his time is to supply labor, $F = w$. This feature of IRS up to some limit (IRStL), as we argued in the Introduction, is commonly present in most occupations that require substantial human capital.

Agents have identical preferences. If an agent consumes s units of the subsistence good and e_i units of variety i of entertainment services, where $i \in E$ and E is the set of varieties of entertainment services available on the market, then his utility is

$$\left(\mu s^{\widehat{\rho}} + \Big(\int_E (h_i e_i)^{\rho}\Big)^{\widehat{\rho}/\rho}\right)^{1/\widehat{\rho}},$$

where $\mu > 0$ measures the relative importance of the subsistence good in the agent's utility function; $\widehat{\rho} \in [0,1)$ measures the substitutability between the subsistence good and entertainment services; and $\rho \in (0,1)$ measures the substitutability between one entertainment service and another. Assume $\widehat{\rho} < \rho$, namely that the subsistence good is less substitutable for entertainment services than one variety of entertainment services is to another.

We set the subsistence good as the numeraire. Let p_i denote the price of variety i of entertainment services and let m denote the income of an agent. Then, the consumption decision that the agent faces is

$$\max_{s,\{e_i\}_{i\in E}} \left(\mu s^{\widehat{\rho}} + \Big(\int_E (h_i e_i)^{\rho}\Big)^{\widehat{\rho}/\rho}\right)^{1/\widehat{\rho}},$$
$$\text{s.t. } s + \int_E p_i e_i \leq m.$$

His demand for the subsistence good and entertainment services is, respectively:

$$\begin{aligned} s &= m \cdot \frac{1}{1+\mu^{1/(\widehat{\rho}-1)} P^{\widehat{\rho}/(\widehat{\rho}-1)}} \\ e_i &= m \cdot f(P,\mu) \cdot h_i^{\rho/(1-\rho)} p_i^{-1/(1-\rho)}, \end{aligned} \tag{2}$$

where the aggregate price index of entertainment services is

$$P := \Big(\int_E (p_i/h_i)^{\rho/(\rho-1)}\Big)^{(\rho-1)/\rho} \tag{3}$$

and the function $f(P,\mu)$ is given by

$$f(P,\mu) := \frac{P^{\frac{\rho-\widehat{\rho}}{(1-\rho)(1-\widehat{\rho})}}}{\mu^{\frac{1}{1-\widehat{\rho}}} + P^{\frac{\widehat{\rho}}{\widehat{\rho}-1}}}.$$

Given price p, the aggregate demand for a particular variety of entertainment services of quality h (also equal to the human capital endowment of the entertainer) is

$$D(p;h) = M \cdot f(P,\mu) \cdot h^{\rho/(1-\rho)} p^{-1/(1-\rho)}, \tag{4}$$

where

$$M := \int_{[0,1]} m_i \tag{5}$$

is aggregate income.

If an agent with human capital h chooses to supply labor and produce the subsistence good, he gets A, which is also the wage of labor employed in the production of entertainment services – that is, $w = A$. Therefore, by (1), the marginal cost of producing entertainment up to scale B is $w\frac{c}{A} = c$. If the agent chooses to live on his human capital, thereby becoming an entertainer, the demand for his variety of services will be given by (4), where he takes the aggregate variables P and M as given. He then sets the price of his services by solving the following decision problem:

$$m(h) = \max_p (p-c)D(p;h), \text{ s.t. } D(p;h) \leq B \tag{6}$$

The agent chooses to provide entertainment services instead of supplying labor only if

$$m(h) \geq A \tag{7}$$

From the envelope theorem and (6), $m'(h) > 0$. There thus exists a critical value $k \in [0,1]$ such that agent i chooses to provide entertainment services, if and only if $i \geq k$, where k is pinned down by

$$m(h_k) = A.^{10} \tag{8}$$

[10]More generally, k satisfies $\left\{\begin{array}{c} k=0 \text{ if } m(h_0) > A \\ k=1 \text{ if } m(h_1) < A \\ m(h_k) = A \text{ if } m(h_0) < A < m(h_1) \end{array}\right\}$. The first two cases capture the possibilities that no one produces the subsistence good and that no one produces any entertainment. With CES preferences,

For $i < k$, agent i earns wage $w = A$, and for $i \geq k$ agent i earns $m(h_i)$, the rents associated with his human capital.

Assuming $E = [k, 1]$, the price index for entertainment services, from (3), is given by

$$P = \Big(\int_k^1 (p_i/h_i)^{\rho/(\rho-1)} \Big)^{(\rho-1)/\rho} \tag{9}$$

Definition 1. *A profile (P, k, M) forms a competitive equilibrium if*

(i) P is given by (9), where p_i solves (6) with $h = h_i$;

(ii) agent i chooses to supply labor if and only if $i < k$ where k is determined by (8);

(iii) Aggregate income is

$$M{=}kA + \int_k^1 m(h_i), \tag{10}$$

where $m(h)$ is defined by (6).[11]

For technical reasons which we will explain, we assume that

$$\max_{x\in[k_0,1]} \frac{h'_x/h_x}{1 + h'_x/h_x \cdot (x - k_0)} < \frac{1}{1 - k_0}, \tag{11}$$

where

$$k_0 = \frac{Bc}{A + Bc}.$$

This condition concerns the distribution of human capital and follows from a more intuitive condition, namely that $[\log h(x)]' < 1/(1 - x)$, [12] which says that $\log h(x)$ does not grow too fast.

4. Two Categories of Technological Advancement

In this section we prove the existence and uniqueness of an equilibrium, and then consider comparative statics with respect to A and B. Here we consider only the case in which the capacity constraint, $D(p; h) \leq B$, is binding for the agents who choose to be entertainers, which effectively requires B to be sufficiently small.[13] The insights derived from this case can then be applied straightforwardly to the case in which the capacity constraint is binding for some entertainers, as we will show. Of course, if it is not binding for any agent then an increase in B will have no effect.

Since the capacity constraint is binding, $D(p, h) = B$, which pins down the price of the variety

neither occurs in equilibrium because if no one produces the subsistence good, the marginal utility from consumption will be infinitely large, and providing it will be very profitable. This argument also applies to the case in which no one provides entertainment services.

[11]We skip the clearing of the subsistence good market, which pins down the fraction of labor used for producing the good, a variable that is not very interesting in the context of this paper.

[12]This comes from $\frac{h'_x/h_x}{1+h'_x/h_x \cdot (x-k_0)} = [1/(h'_x/h_x) + x - k_0]^{-1} < [1 - x + x - k_0]^{-1} = \frac{1}{1-k_0}$.

[13]An exact condition for this is provided in Subsection 4.1.

of entertainment services provided by agent i which, with $D(p,h)$ given by (4), is:

$$p_i = \Big(\frac{Mf(P,\mu)}{B}\Big)^{1-\rho} h_i^{\rho}. \tag{12}$$

Substituting (12) into (6), the rent captured by entertainer i is

$$m(h_i) = \Big[\Big(\frac{Mf(P,\mu)}{B}\Big)^{1-\rho} h_i^{\rho} - c\Big]B. \tag{13}$$

With p_i given by (12), the aggregate price, from (9), is

$$P = \Big(\frac{Mf(P,\mu)}{B}\Big)^{1-\rho} H_k^{\rho-1}, \tag{14}$$

where

$$H_k := \Big\{\int_k^1 h_i^{\rho}\Big\}^{\frac{1}{\rho}}. \tag{15}$$

From (14), $\Big(\frac{Mf(P,\mu)}{B}\Big)^{1-\rho} = PH_k^{1-\rho}$. Substituting this into (13), the rent captured by entertainer i is

$$m(h_i) = BPH_k^{1-\rho}h_i^{\rho} - Bc, \tag{16}$$

where the first term is total revenue, which we denote by $R(h_i)$, which is proportional to capacity, the general price of entertainment services, and the entertainer's human capital raised to the power ρ. The second term represents the labor costs.

Equation (14) implies that $M/(BH_k) = P^{\frac{1}{1-\rho}}/f(P,\mu)$. With $f(P,\mu) = \frac{P^{\frac{\rho-\widehat{\rho}}{(1-\rho)(1-\widehat{\rho})}}}{\mu^{\frac{1}{1-\widehat{\rho}}} + P^{\frac{\widehat{\rho}}{\widehat{\rho}-1}}}$, it follows that

$$P + (\mu P)^{\frac{1}{1-\widehat{\rho}}} = \frac{M}{BH_k}. \tag{17}$$

This equation and equation (16) together imply that an entertainer acquires a fraction of aggregate income that is proportional to his human capital raised to the power ρ:

$$R(h_i) = \frac{1}{1+\mu^{\frac{1}{1-\widehat{\rho}}}P^{\frac{\widehat{\rho}}{1-\widehat{\rho}}}} \cdot M \cdot \frac{h_i^{\rho}}{H_k^{\rho}}. \tag{18}$$

Here, the first term is the fraction of aggregate income, M, that is spent on entertainment[14]– note that for the Cobb-Douglas case, where $\widehat{\rho} = 0$, it is $1/(1+\mu)$, it is independent of the price of entertainment, P. The third term is the fraction of spending on entertainment services for agent i. Note that $\int_k^1 h_i^{\rho} H_k^{\rho} = 1$, which is proportional to h_i^{ρ}. This is because the price that an entertainer

[14]From (2), the fraction of aggregate income spent on the subsistence good is $\frac{1}{1+\mu^{1/(\widehat{\rho}-1)}P^{\widehat{\rho}/(\widehat{\rho}-1)}}$. Therefore, the fraction spent on entertainment services is $1 - \frac{1}{1+\mu^{1/(\widehat{\rho}-1)}P^{\widehat{\rho}/(\widehat{\rho}-1)}} = \frac{1}{1+\mu^{\frac{1}{1-\widehat{\rho}}}P^{\frac{\widehat{\rho}}{1-\widehat{\rho}}}}$.

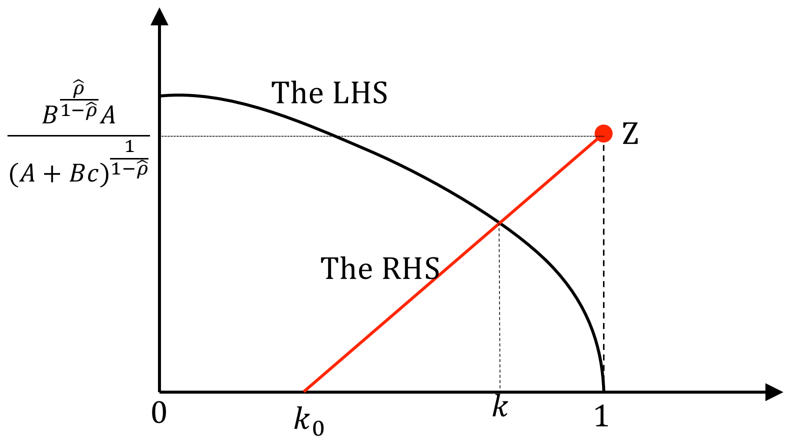

Figure 1: The Existence and Uniqueness of Equilibrium

charges, by (12), is proportional to his human capital raised to the power ρ.

Agent k, who is indifferent between becoming an entertainer or supplying labor, is identified by the condition $m(h_k) = A$. Applying (16), for $i = k$ it follows that

$$PH_k^{1-\rho}h_k^{\rho} = c + \frac{A}{B}. \tag{19}$$

which corresponds to equilibrium condition (ii).

With (16), condition (iii) becomes

$$M = kA - (1-k)cB + BPH_k. \tag{20}$$

The simultaneous equations (17), (19) and (20) then pin down the equilibrium values of (P, k, M).

Canceling out M with (17) and (20) and substituting for P with the solution from (19), we have an equation that pins down k:

$$\mu^{\frac{1}{1-\hat{\rho}}} H_k^{\frac{\rho-\hat{\rho}}{1-\hat{\rho}}} h_k^{\frac{-\rho}{1-\hat{\rho}}} = (A/B + c)^{\frac{-\hat{\rho}}{1-\hat{\rho}}}(k - k_0), \tag{21}$$

with $k_0 = \frac{Bc}{A+Bc}$.

Since $\rho - \hat{\rho} > 0$, $H_k^{\frac{\rho-\hat{\rho}}{1-\hat{\rho}}}$ increases with $H_k = \{\int_k^1 h_i^{\rho}\}^{\frac{1}{\rho}}$, which decreases with k. Since $\rho > 0$, $h_k^{\frac{-\rho}{1-\hat{\rho}}}$ decreases with h_k which, by assumption, increases with k. Moreover, $H_1 = 0$. Therefore, the left hand side (LHS) of (21) decreases from a positive number to 0 with k ascending from k_0 to 1. But with this movement of k, the right hand side (RHS) of (21) linearly increases from 0 to $1 - k_0 = A/(A + Bc) > 0$. Both sides are depicted in Figure 1 below.

This argument clearly shows that:

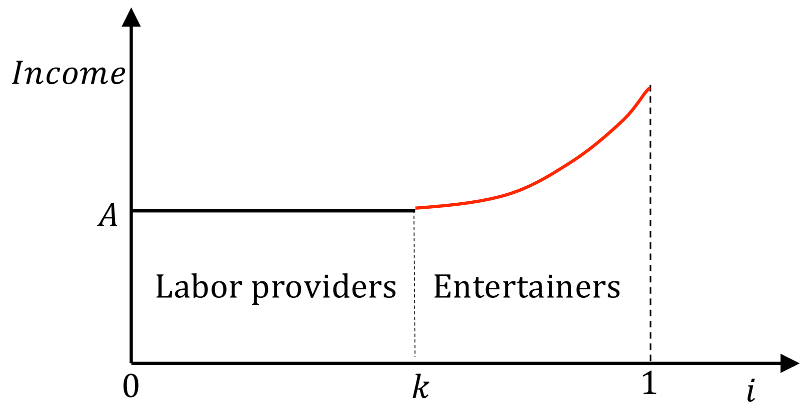

Figure 2: The Equilibrium Income Distribution

Proposition 1. *A unique equilibrium exists, for* $k \in (k_0, 1)$.

The economic intuition for the existence and uniqueness of an equilibrium can be understood in light of the CES preference and the market forces at play. The former ensures that both the subsistence good and some entertainment services are provided in any equilibrium, such that the population is divided between these two career types – i.e., k lies between 0 and 1. Market forces then ensure the uniqueness of this division: if too many agents choose to provide labor and produce the subsistence good, then the entertainment services will be costly, which will induce entry into entertainment service provision. Conversely, if too few agents provide labor there will be entry into production of the subsistence good.

Next consider the equilibrium income distribution. Agents $i < k$ choose to provide labor and earn income A, while agents $i \geq k$ become entertainers, where their income, m_i, is related to their human capital according to (16). Substituting $PH_k^{1-\rho} = (c + A/B)h_k^{-\rho}$ – from (19) – into (16) we find that for $i \geq k$,

$$m_i = (Bc + A)\frac{h_i^\rho}{h_k^\rho} - Bc. \tag{22}$$

Entertainers' income is therefore proportional to their human capital raised to the power ρ. The overall distribution of agents' income is illustrated in the following figure.[15]

[15]The figure is based on the assumption that h_i is a convex function of i so that m_i, though a concave function of h_i, is convex in i. Roughly, the assumption is that within a typical talent distribution, there are a small number of people at the top who are much more talented than the rest – a view that seems consistent with the evidence.

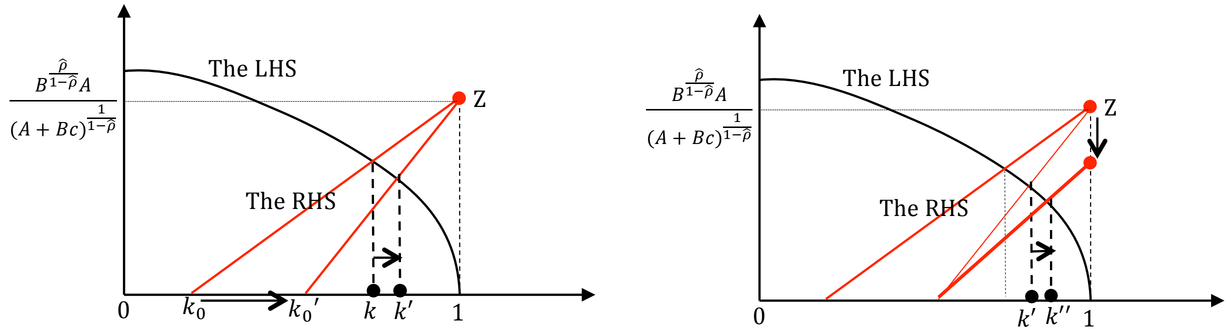

Figure 3: The effect of an increase in B on k. The left panel: an increase in B moves k_0 to k', which increases k to k'. The right panel: if point Z moves down, then k is shifts further to k''

4.1. The Effects of Type-B Technological Progress

Here we consider the comparative statics with respect to B.[16] We first consider how an increase in B affects the occupational choice of the agents, captured by k. To begin with, it has no effect on the income associated with providing labor, which is fixed at A. As for the income of an entertainer, an increases in B raises their labor costs because now they need to hire more labor to maintain a larger capacity. On the revenue side, there are three conflicting effects. First, a positive effect: a rise in B enlarges the entertainers' capacity and thereby increases their revenues. Second, a negative effect: since all entertainers are equally exposed to the rise in capacity, each individual entertainer faces fiercer competition, which reduces revenues (all else equal). And third, an increase in B may affect aggregate income, positively or negatively, thereby affecting entertainers' revenues.

The equilibrium k is determined by equation (21), where the LHS is independent of B. As a result, the curve in Figure 3, representing the LHS, is invariant to an increase in B. The RHS, on the other hand, is affected in two ways. First, $k_0 = Bc/(A + Bc)$ increases with B so that k_0 moves rightward. Second, the uppermost part of the line, Z, may shift up or down. If the position of Z does not change, while k_0 moves to the right, clearly k will also move to the right, as is illustrated in the left panel of Figure 3. If Z moves down then k shifts further to the right, as is illustrated in the right panel of the Figure.

The height of Z is $(A/B+c)^{\frac{-\hat{\rho}}{1-\hat{\rho}}}(1-k_0) = AB^{\frac{\hat{\rho}}{1-\hat{\rho}}}/(A+Bc)^{\frac{1}{1-\hat{\rho}}}$. Z moves down with an increase in B if

$$\frac{dAB^{\frac{\hat{\rho}}{1-\hat{\rho}}}/(A+Bc)^{\frac{1}{1-\hat{\rho}}}}{dB} \leq 0,$$

[16]Since we are examining the case in which the capacity constraint, $D(p;h) \leq B$, is binding, the comparative statics are based on the assumption that it remains binding following any change. Later we consider the comparative statics for the case in which the capacity constraint is binding for some share of entertainers.

which is equivalent to

$$c \geq \frac{\widehat{\rho}}{1-\widehat{\rho}} \cdot \frac{A}{B}. \tag{23}$$

It follows that

Proposition 2. *If $c \geq \frac{\widehat{\rho}}{1-\widehat{\rho}} \cdot \frac{A}{B}$, then $dk/dB > 0$, that is, with a rise in the limit of IRS, fewer agents choose to provide entertainment services, and the number of varieties provided falls.*

Proof. We relegate the proof to Appendix A. □

The Cobb-Douglas case ($\widehat{\rho} = 0$) provides an example in which Proposition 2 holds. In this case the fraction of aggregate income spent on entertainment is fixed at $1/(1+\mu)$ by (18). If no entertainers exit (and aggregate income does not change), then each of them now receives the same amount of revenue, but faces increased labor costs (in order to maintain the larger capacity). Thus, the previously marginal entertainer, who was indifferent between the two occupational choices, now finds it unprofitable to employ their human capital. In other words, they are squeezed out, leaving a smaller number agents to share the revenue pool and thereby increasing the revenue allocated to the remaining entertainers.

Besides having implications for the occupational choices of agents, Proposition 2 also implies that the lower end entertainers lose from an increase in B. Consider those entertainers endowed with a level of human capital close to the marginal entertainer's, and who are therefore squeezed out of the entertainment business with the increase in B. Before the rise in B they earned strictly more than the wage of labor, A, as they strictly preferred being an entertainer to providing labor. After the increase in B they are squeezed out, and subsequently provide labor, and therefore earn the wage of labor. These agents therefore lose. This result is stated as the proposition below and is formally proved.

Proposition 3. *There exists $\widehat{k} > k$ such that $dm_i/dB < 0$ for $i \leq \widehat{k}$ – namely, the lower end entertainers lose from an increase in the limit of IRS.*

Proof. We need only show that $dm_i/dB < 0$ for $i = k$. When this is the case, the Proposition follows from the fact that dm_i/dB is continuous in i. By (22), $\frac{dm_i}{dB} = h_i^{\rho}/h_k^{\rho} \cdot [c - (A+Bc) \cdot \rho \cdot (\log h_k)' \cdot \frac{dk}{dB}] - c$. At $i = k$, therefore, $\frac{dm_i}{dB} = c - (A+Bc) \cdot \rho \cdot (\log h_k)' \cdot \frac{dk}{dB} - c = -(A+Bc) \cdot \rho \cdot (\log h_k)' \cdot \frac{dk}{dB} < 0$ because $(\log h_k)'$ is assumed to be positive and $\frac{dk}{dB} > 0$ by Proposition 2. □

An additional effect of a rise in B is that relatively high-quality entertainers gain relatively more due to the capacity enlargement. This is because the increase in B affects an entertainer's revenue in proportion to the entertainer's human capital (raised to the power ρ). Intuitively, a higher-quality entertainer charges a higher price which, by (12), is in proportion to h_i^ρ. This result leads to the following proposition.

Proposition 4. *Under assumption (11), dm_i/dB increases with m_i. That is, the greater the current income of an entertainer, the more the entertainer gains (or the less he loses) from an increase in the limit of IRS.*

Proof. We relegate the proof to Appendix B. □

However, if the condition assumed in (11) does not hold, it may be the case that dm_i/dB decreases with m_i – that is, the greater the present income of an entertainer is, the less it gains, or the more it loses, from an increase in the limit of IRS. In Appendix C, we construct an example of this case. Intuitively, this case is driven by the third effect noted above arising from an increase in B, namely the effect that operates through aggregate income. By (18), if aggregate income changes by ΔM, other things fixed, the revenue of entertainer i changes by $\Delta R(h_i) = \frac{1}{1+\mu^{\frac{1}{1-\hat{\rho}}} P^{\frac{\hat{\rho}}{1-\hat{\rho}}}} \frac{h_i^\rho}{H_k^\rho} \cdot \Delta M$. Thus, if $\Delta M < 0$, the loss to the entertainer is proportional to his human capital, to the power ρ. If this loss outweighs the gain due to the positive effect arising from the loosening of the capacity constraint (which is the mechanism behind Proposition 3), then the net effect is that revenue falls when B rises, and the net loss is proportional to h_i^ρ. However, this case is unlikely in reality due to the fact that the economy consists of hundreds of occupations (while in the model there are only two) and any change in one occupation is unlike to have a large effect on aggregate income. That is, ΔM should be small due to any change in the limit of IRS for any particular occupation. See Appendix C for a full explication of this case.

By Proposition 4, if an entertainer's human capital is high enough the increment in revenue will outweigh the increment in cost, and the entertainer acquires a net gain from capacity enlargement. To state this formally, let

$$\Omega(\rho) := \frac{\rho \cdot h_k'/h_k}{1 + \rho \cdot h_k'/h_k \cdot (k - k_0)}.$$

By assumption (11), $\Omega(\rho) \cdot A/(A + Bc) < 1$.[17] We can then state the following:

Lemma 1. *$dm_i/dB > 0$, namely agent i's income rises with an increase in the limit of IRS, if*

$$\frac{h_i^\rho}{h_k^\rho} > \frac{1}{1 - \Omega(\rho) \cdot A/(A + Bc)}. \tag{24}$$

[17]Given k, $\Omega(\rho)$ increases with ρ. Therefore, $\Omega(\rho) \leq \Omega(1) = \frac{h_k'/h_k}{1+h_k'/h_k \cdot (k-k_0)}$, which by the assumption is smaller than $\frac{A+Bc}{A}$.

Proof. We relegate the proof to Appendix D. □

Condition (24), however, is not easy to check. This is because k is determined in equilibrium and depends on the distribution of human capital (specifically, the functional form of $h(i)$). Below, we present an approach, dispensing with k, to get a condition under which the top entertainers gain on net from an increase in the limit of IRS.

Let $f(k_0, y)$ denote the unique solution for $t \in [k_0, 1]$ in

$$t - k_0 = y(1-t)^{\frac{\rho-\widehat{\rho}}{\rho(1-\widehat{\rho})}},$$

and let

$$D := \mu^{\frac{1}{1-\widehat{\rho}}}(A/B + c)^{\frac{\widehat{\rho}}{1-\widehat{\rho}}}.$$

Lemma 2. *Assume $h_1 > 1$. If $h_1 \geq \zeta \cdot h(f(k_0, D \cdot \zeta^{\frac{\rho}{1-\widehat{\rho}}}))$, then $h_1 > \zeta \cdot h_k$.*

Proof. We relegate the proof to Appendix E. □

The two lemmas above lead to the following proposition, which gives a condition for the distribution function of human capital under which the top entertainers' income strictly increases with B. Let

$$\xi := [\frac{1}{1 - \Omega(\rho) \cdot A/(A + Bc)}]^{\frac{1}{\rho}}.$$

Proposition 5. *If $h_1 > 1$ and $h_1 \geq \xi \cdot h(f(k_0, D \cdot \xi^{\frac{\rho}{1-\widehat{\rho}}}))$, then $dm_1/dB > 0$, i.e., the top entertainers gain on net from an increased limit of IRS.*

This proposition, together with Proposition 2 which states that entertainers at the bottom of the distribution are pushed out of the entertainment occupation into providing unskilled labor, implies that an increase in B causes the change in the income distribution depicted in Figure 4.

4.2. The Effects of Type-A Technological Progress

We now consider the comparative statics with respect to A, the productivity of labor. We start by considering how an increase in A affects the agents' occupational choices. First, a rise in A directly increases the income of labor. This effect alone would induce more agents to provide labor and fewer to become entertainers. However, this direct effect is countered by an indirect effect. By increasing aggregate income, an increase in A will raise the demand for entertainment, which induces more agents to become entertainers and fewer to provide labor. The balance between these two forces

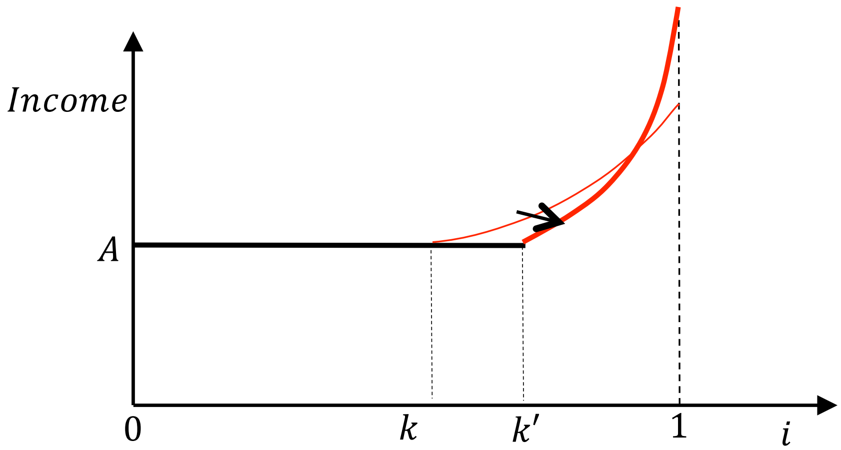

Figure 4: An increase in B squeezes the lower-end entertainers out, and raises the income of the upper-end entertainers.

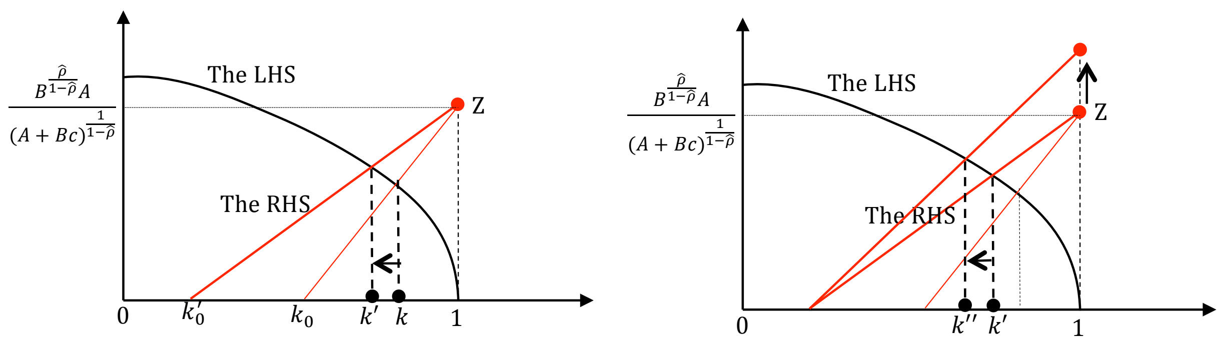

Figure 5: The effect of an increase in A on k. The left panel: an increase in A moves k_0 to the left, which decreases k to k'. The right panel: if Z moves upward, then k falls further to k''

determines shifts in k, reflecting the number of agents in the entertainment occupation. Below we show that if the condition for Proposition 2 – namely, (23) – holds, then the indirect income effect dominates the direct effect and more agents become entertainers (i.e., k falls).

To show this graphically, we return to equation (21), which determines equilibrium k. The two sides of the equation are depicted in Figure 5. The LHS, represented by the curve, is independent of A. Therefore, the curve in Figure 5 does not shift with an increase in A. As for the RHS, an increase in A shifts the straight line in Figure 5 in two ways. First, $k_0 = Bc/(A+Bc)$ falls with an increase in A and the position of k_0 shifts leftward. Second, the uppermost part of the line, Z, may move up or down. If the position of Z does not change, but k_0 moves leftward, then so does k, as is illustrated by the left panel of the Figure. If Z moves upward, then k falls further, as is illustrated by the right panel of the Figure.

The height of Z is $(A/B+c)^{\frac{-\widehat{\rho}}{1-\widehat{\rho}}}(1-k_0) = AB^{\frac{\widehat{\rho}}{1-\widehat{\rho}}}/(A+Bc)^{\frac{1}{1-\widehat{\rho}}}$. Z moves upward with an increase in A if

$$\frac{dAB^{\frac{\widehat{\rho}}{1-\widehat{\rho}}}/(A+Bc)^{\frac{1}{1-\widehat{\rho}}}}{dA} \geq 0,$$

which is equivalent to (23). Therefore,

Proposition 6. *If $c \geq \frac{\widehat{\rho}}{1-\widehat{\rho}} \cdot A/B$ – i.e., (23) holds – then $dk/dA < 0$. Thus, with a rise in the productivity of labor, more agents choose to provide entertainment services, and the number of varieties therefore increases.*

Proof. We relegate the proof to Appendix F. $\square$

Again we use the Cobb-Douglas case (where $\widehat{\rho} = 0$) for intuition. If A increases by one percent, then labor's income increases by the same amount. If entertainers' income also increases by one percent – so that k is unmoved – then aggregate income also increases by one percent. In the Cobb-Douglas case a fixed fraction of this rise in income goes to entertainers. As a result, each entertainers' revenue, in particular the marginal entertainers', increases by one percent, while their (labor) costs stay the same, equal to Bc. Therefore, the marginal entertainers' income increases by more than one percent, i.e., more than the increment of the labor suppliers' income. By (17) and (20), if $\widehat{\rho} = 0$ (i.e. the Cobb-Douglas case), aggregate income $M = \frac{1+\mu}{\mu}[kA - (1-k)Bc]$. Therefore, if k does not decrease, then a one percent increase in A induces M to increase by more than one percent. Thus, the marginal entertainer now strictly prefers becoming an entertainer. This implies that someone with lower human capital enters the entertainment occupation – i.e., k goes down.

Note that an increase in A directly benefits unskilled labor, but this is not the case for entertainers. From (1), the marginal cost of production is $w \cdot c/A = c$, independent of A. It is in this sense that we can say that *an increase in A is biased toward (low-skill) labor.* However, the argument above suggests that all entertainers gain more from an increase in A than laborers, due to general equilibrium effects. This is strictly proved in the following proposition.

Proposition 7. *For $i \geq k$, $\frac{dm_i}{dA} > 1$ and $\frac{dm_i}{dA}$ increases with m_i.*

Proof. By (22), $\frac{dm_i}{dA} = \frac{h_i^\rho}{h_k^\rho} + (Bc+A)(-\rho)\frac{h_i^\rho}{h_k^{\rho+1}} \cdot h'_k \cdot \frac{dk}{dA} = \frac{h_i^\rho}{h_k^\rho} \cdot [1 + (Bc+A)(\log h_k)' \cdot (-\rho\frac{dk}{dA})]|_{-\rho\frac{dk}{dA}>0 \text{ (by Prop. 5)}} > \frac{h_i^\rho}{h_k^\rho} \geq 1$. Moreover, by (22), $\frac{h_i^\rho}{h_k^\rho} = \frac{m_i+Bc}{A+Bc}$. Then, $\frac{dm_i}{dA} = \frac{m_i+Bc}{A+Bc} \cdot [1 + (Bc+A)(\log h_k)' \cdot (-\rho\frac{dk}{dA})]$ and increases with m_i. $\square$

The proposition is driven by two effects generated by an increase in A. One is the effect on occupational choice, as shown in Proposition 6. This effect ensures that the marginal entertainer gains more from the increase than does labor. The other effect is due to the change in aggregate income, which increases with a rise in A. The fraction of this increase that an entertainer acquires

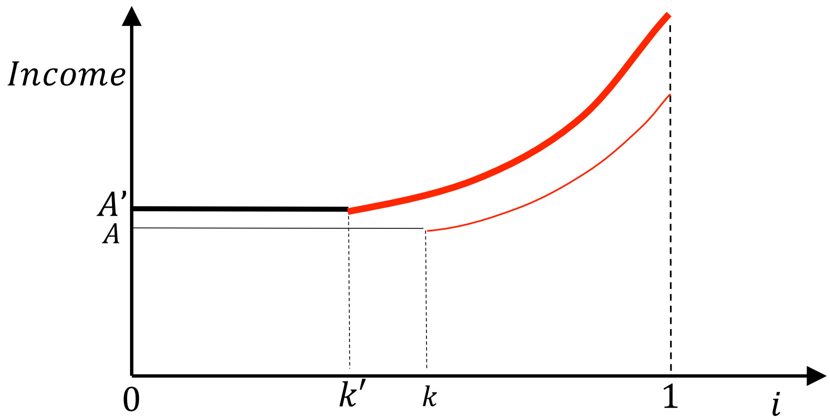

Figure 6: An increase in A raises all agents’ incomes while also increasing income inequality.

is in proportion to his human capital (to the power ρ) – by (18), $\Delta R(h_i) = \frac{1}{1+\mu^{\frac{1}{1-\hat{\rho}}} P^{\frac{\hat{\rho}}{1-\hat{\rho}}}} \frac{h_i^\rho}{H_k^\rho} \cdot \Delta M$, proportional to h_i^ρ – and therefore in proportion to his earnings.

The proposition states that the more an entertainer currently earns, the greater is the growth in his income from an increase in A. Intuitively, when the economy becomes richer, agents spend more on entertainment services. This rise in spending is allocated more toward more expensive entertainment, which is provided by more talented entertainers who therefore earn even more.

Therefore, a rise in the productivity of unskilled labor both directly benefits the lowest income workers while simultaneously increasing income inequality. The effect on the income distribution is illustrated in Figure 6.

4.3. Discussion

When the Capacity Constraint Is Non-Binding for Some Entertainers

If the capacity constraint is non-binding for some entertainers, then these entertainers’ human capital will lie at the lower end of the distribution. The demand for an entertainer’s services, by (4), is proportional to $h_i^{\rho/(1-\rho)}$. Thus, the profit-maximizing output in the absence of the capacity constraint increases with h_i. As a result, if it is binding for agent i then it is binding for all the agents $i' \geq i$, and if it is not binding for agent i, then neither is it for any agent $i' \leq i$. Thus, if and only if the capacity constraint is binding for the marginal agent k, will it bind for all entertainers. Since the entertainers’ problem is given by (6), in the absence of a capacity constraint, the optimal price is c/ρ. The constraint is binding for agent k if he cannot reach this price by supplying enough output, namely if the price pinned down by the binding capacity constraint, p_k, is no less than c/ρ.

This condition, with p_k given by (12) with $i = k$, formally is:

$$\Big(\frac{Mf(P,\mu)}{B}\Big)^{1-\rho} h_k^{\rho} \geq \frac{c}{\rho}. \tag{25}$$

If the capacity constraint is binding for some share of entertainers and non-binding for the remainder, the argument above implies that there exists $j \in (k, 1)$ such that it is non-binding for $i < j$ and binding for $i > j$. In particular, it is non-binding for the marginal entertainer, k. In this case, the propositions derived above all hold qualitatively.

Proposition 1 still holds. The unique equilibrium still exists, and is driven by the same economic forces as before. If too many agents choose to provide labor and produce the subsistence good, then the entertainment services will be expensive, which will induce further entry. Conversely, if too few agents provide labor there will be entry into production of the subsistence good.

Proposition 2 still holds, and therefore so does Proposition 3 which is driven by Proposition 2; that is, an increase in B squeezes the entertainers at the lower end out of the profession (i.e., $dk/dB > 0$). In fact, this holds even under a less strict condition. Specifically, the marginal entertainer, now with a non-binding capacity constraint even before the increase in B, gains nothing from this increase. Therefore, the positive effect due to the loosening of the capacity constraint is now absent. As a result, there is now an additional reason that he is adversely affected by the increase and squeezed out of the entertainment occupation.

Propositions 4 and 5 hold qualitatively, that is, the entertainers currently earning more will gain more or lose less from an increase in B, and the top entertainer, if his human capital is high enough, gains on net from this increase. Both propositions are driven by the fact that entertainers with higher human capital – who therefore earn more – gain more from a capacity enlargement, again due to the fact that they are able to charge higher prices which, by (12), are in proportion to their human capital (to the power ρ). But the exact conditions for these two propositions will change since M, P and k will be ruled by a different profile of equilibrium conditions.

Proposition 6 holds qualitatively – namely, an increase in A induces more agents to live on human capital – though the exact condition may change. Consider the Cobb-Douglas case. A one percent increase in A raises labor's income by the same amount. Suppose that this affects all entertainers in the same way, so that k is unmoved. Then aggregate income rises by one percent, which means the revenue of the marginal entertainer increases by the same amount. But his labor cost stays the same. As a result, his income rises by more than one percent, thus making the marginal entertainer strictly prefer the entertainment business and thus inducing entry into entertainment. This intuitive argument suggests that a one percent increase in A moves k leftward.

Proposition 7 still holds, namely more talented (and thus richer) entertainers gain more from an increase in A. Again it is driven by the same effect: an increase in A affects entertainers' income by raising aggregate income, and the fraction of this increase that an entertainer acquires is in proportion to his human capital level (to the power ρ).

Unaffected Occupations

The model thus far assumes that there is only one type of human capital, which is used to provide entertainment services. In reality, there are many types of human capital associated with many types of occupations. Moreover, as we argued in the Introduction, recent ICT innovations have led to a rise in the limit of IRS for some occupations, while for others these innovations have had little impact. This subsection examines how the increase in the limit of IRS for one occupation, which we refer to as the "affected" occupation, may impact another occupation, for which the limit of IRS is unchanged, and which we refer to as the "unaffected" occupation.

Suppose that, in addition to the continuum of agents previously described, there is now another continuum of agents, $j \in [0,1]$. Agent j has one unit of labor and $\widetilde{h}_j$ of another type of human capital which is needed for childcare services (e.g., patience or tolerance of noise). Thus, each agent j makes an occupational choice between labor and childcare. The provision of childcare is subject to IRS up to limit $\widetilde{B}$:

$$y = \left\{ \begin{array}{c} \frac{A}{\widetilde{c}}L \text{ if } L \leq \frac{\widetilde{c}}{A}\widetilde{B} \\ \widetilde{B} \text{ if } L > \frac{\widetilde{c}}{A}\widetilde{B} \end{array} \right\}.$$

Each agents' utility is given by

$$\left(\mu s^{\widehat{\rho}} + \big(\int_E (h_i e_i)^{\rho}\big)^{\widehat{\rho}/\rho} + \big(\int_F \big(\widetilde{h}_j f_j)^{\widetilde{\rho}}\big)^{\widehat{\rho}/\widetilde{\rho}}\right)^{1/\widehat{\rho}},$$

where f_j is the consumption of the variety of childcare services provided by agent j and e_i is consumption of a variety of entertainment services as before.

What will be the effect of an increase in B (the limit of IRS for entertainers) on the childcare workers' incomes? It is straightforward to carry out the formal analysis for this extended model, but instead we only provide the intuition here. An increase in B affects childcare workers in the following two ways.

1. A price effect: entertainment services become relatively cheaper. As is typical in a consumers' decision problem, the price reduction generates two conflicting effects on the spending of each agent on childcare: a negative substitution effect and a positive income effect. For the CES case that we are considering, if $\widehat{\rho}$ is positive, that is, if entertainment and childcare are substitutes in consumption, then the negative substitution effect dominates the positive income effect and childcare workers are adversely affected. If $\widehat{\rho}$ equals zero (the Cobb-Douglas case), then these two effects exactly

offset each other and childcare workers are not affected. Finally, the net effect will be positive if the services provided by the unaffected occupation and those by the affected occupation are complements ($\widehat{\rho} < 0$).[18]

2. An aggregate income effect: aggregate income may increase or decrease with the increase in B, which may then affect childcare workers positively or negatively.

In addition, we can derive a parallel formula to (18): a childcare worker with higher human capital acquires a greater share of aggregate spending on childcare.

Finally, note that if B is unchanged then there is no "affected occupation". In this case, childcare workers and entertainers are symmetric. Therefore, an increase in A affects both occupations in the same way as explained above.

4.4. Toward an Empirical Investigation

An important observation from the discussion above is that an increase in B affects all practitioners in the unaffected occupation (childcare, in this case) *in the same way*: If one practitioner gains, then all gain; if one loses, then all lose. This is because both the price effect (point 1 above) and the aggregate income effect (point 2 above) affect a childcare worker's income through the aggregate spending on childcare services. If the combination of these two effects increases (decreases) this spending, then all childcare workers gain (lose) from an increase in the limit of IRS for the entertainers. Moreover, since higher human-capital endowed childcare workers acquire a relatively larger fraction of this aggregate spending, these workers gain (lose) relatively more from an increase (decrease) in this spending. Here we lay the groundwork for the empirics by comparing these two predictions of the model with Propositions 3 and 4, which together state that an increase in B increases income inequality within the affected occupation.

Suppose that between period t and $t+1$, there is an increase in the limit of IRS for an occupation. Consider the following regression equation:

$$W_{yi,t+1} - W_{yit} = \alpha_y + \beta_y(W_{yit} - \underline{W_{yit}}) + \epsilon_{yit}, \tag{26}$$

where y indicates the affected ($y = 1$) or unaffected ($y = 0$) occupation, i denotes an agent in the occupation in period t, W is the wage of the agent and $\underline{W}$ is the lower bound wage within the occupation (perhaps the local minimum wage). In addition, ϵ_{yit} contains unobserved factors that affect wage growth. For the affected occupation Proposition 3 predicts that $\alpha_1 < 0$ (i.e., the low end practitioners lose) and Proposition 4 predicts that $\beta_1 > 0$ (i.e., the more a practitioner earns,

[18] By (2), if the price of entertainment services, P, decreases, the fraction spent on the subsistence good, $\frac{1}{1+\mu^{1/(\widehat{\rho}-1)}P^{\widehat{\rho}/(\widehat{\rho}-1)}}$, decreases too, unless $\widehat{\rho} \leq 0$ (but we assume $\widehat{\rho} \geq 0$ – namely, that the subsistence good and services are substitutes).

the more she gains from the increase in the limit of IRS for the occupation). For the unaffected occupation, the discussion above implies that α_0 and β_0 are the same sign. For instance, if $\alpha_0 > 0$, which means that the low-end practitioners gain, then it must be the case that total spending on the services of the unaffected occupation have risen. Given that the top earners acquire a larger fraction of this additional spending, they gain more, which implies that $\beta_0 > 0$. A similar argument holds for the case in which $\alpha_0, \beta_0 < 0$.

While the argument above does not clearly indicate the sign of $\beta_1 - \beta_0$, an additional condition ensures that the sign is positive: the services provided by the unaffected occupations must be substitutes for, rather than complements to, the services provided by the affected occupations. In this case, the price effect is negative (for the unaffected occupations) which, all else constant, implies a negative β_0. At the same time, assuming there is no substantial difference in the distribution of human capital between the two occupations, the aggregate income effect influences both the affected occupations and the unaffected occupations identically, so that this effect represents a common shift in the values of β_1 and β_0 and will be canceled out in the value of $\beta_1 - \beta_0$. On the other hand, β_1 will be positive for the affected occupation, driven by the fact that the top earners in the occupation, who charge higher prices, gain more from a capacity enlargement, in line with Proposition 4. Thus, $\beta_1 - \beta_0 > 0$.

Moving closer to a final specification, we note that this discussion implies that $\beta > 0$ in the following regression:

$$W_{i,t+1} - W_{it} = \tilde{\alpha} + \beta_0(W_i - \underline{W_{it}}) + \beta\big[OT_i \times (W_{it} - \underline{W_{it}})\big] + \epsilon_{it}, \tag{27}$$

where OT represents the "occupation type", such that $OT = 1$ for affected occupations and 0 for unaffected occupations. As we will see below, there is little reason to believe that the affected and unaffected occupations that we compare are complements, and are more likely to be substitutes, in support of the use of a specification based on (27).

5. U.S. Empirical Patterns

In this section we bring the comparative statics results from Section 4 to the data. In particular, we show that a portion of the recent growth in U.S. inequality can be attributed to the interaction of new information and communication technologies (ICT), such as the Internet, with distinct occupational features, as described by the theoretical model and discussion above. Throughout, we exploit data from the U.S. Census for 1990 and 2000 and the American Community Survey (ACS) for 2010.[19]

First, we briefly recap the significance of the key model parameters, A and B. In the model, A represents the productivity of labor and, since the model sets aside the role of physical capital in production, can be thought of as reflecting Total Factor Productivity. Parameter B in the model represents the limit of IRS for an occupation, and may vary across occupations. In real life, this limit can be generated in two different ways. First, it may capture a feature of the production technology associated with the provision of services by the occupation. More specifically, we assume that the services can be produced, after some fixed costs, at a constant marginal cost up to scale B. For the example of childcare, the fixed costs are the opportunity costs of the time of a childcarer, the marginal cost is the cost of attention put on a child, and B is the number of children beyond which she cannot take care of without the quality of her service being seriously compromised. For the example of the production of music, the fixed costs are the costs of creating a song, which are usually big, and the marginal cost is the cost of making a copy of it, which is small, and B is the number of the copies beyond which the quality of a newly made copy is much lower – probably this number is infinite. Second, the limit of the IRS in the model may be determined by information and search frictions. For a singer, therefore, the limit of IRS is set not by the technology of making copies, but by the range of people who know his songs well and are willing to buy them.[20] [21]

In bringing these ideas to the data, we note that the comparative statics with respect to A are more difficult to test than those with respect to B, due to the fact that A affects all occupations equally, whereas B is occupation-specific. In other words, the nature of B allows us to exploit the panel dimension of our data. As a result, in our empirical tests we focus narrowly on the comparative statics implications of the model with respect to B. The idea is to exploit the variation noted in the Introduction, namely that the expansion of the Internet has had a differential effect on the limit of IRS for different occupations. To test the model's Propositions, we would ideally like to classify occupations along a spectrum according to the degree to which the limit of IRS (i.e., B) has increased for each occupation. Since this would be quite challenging to do, we instead focus on identifying a group of occupations whose limits of IRS are likely to be particularly responsive to the advent of new ICT. This will allow us to then exploit the rapid growth in Internet access post-2000 in order to discern the differential response of the wage distribution across occupations

[19] The data come from IPUMS (see Ruggles, Alexander, Genadek, Goeken, Schroeder and Sobek (2010))

[20] Note that if there is no IRS associated with an occupation, then reductions in information or search frictions (or any other potential shocks to B) will have no effect. For instance, barbers are relatively unaffected by the growth in global Internet access.

[21] We also note that, in the model, each professional sells to all the agents and each agent buys from all the professionals. But this is because in the model the consumers are homogenous, with the same utility function. In reality, no musician sells to the entire population (with the possible exception of Michael Jackson in 1982) and no one buys music from all musicians. But if we aggregate the consumption of all music and imagine that it is consumed by one "representative agent", then the model makes sense in terms of tracking aggregate demand for each musician.

that, due to their features, are likely to be more or less responsive to ICT innovations. For instance, the scale of operation for a musician – namely, the extent to which people in the economy know of the musician's music – will increase with the invention and expansion of the Internet, and more so than for most other occupations. The model then predicts that the wage distribution for musicians will be particularly affected by the Internet, in line with the comparative statics above.

In order to be systematic in identifying the most affected occupations, we start with the idea that there are two primary features that determine whether the impact of ICT on the limit of IRS for an occupation will be large. First, the occupation output should be able to exploit the new technology, which will be the case when the stream of services produced by the occupation "can be delivered electronically over long distances with little or no degradation in quality", to borrow a concept used by Blinder (2009). In effect, worker output should be able to be digitized. Second, the stream of services produced by the occupation should naturally exhibit IRS. This will be the case, for instance, when the occupation output is sufficiently non-rival – i.e., when the cost of providing the service to an additional consumer is (nearly) zero.[22] We refer to occupations that possess these two features as "ICT-affected" occupations.

Again, the clearest example of this type of occupation is musicians, whose stream of services can be easily digitized while the marginal cost of producing an extra unit is effectively zero. Other occupations tend to be less obvious candidates, but we believe that while it is difficult to precisely quantify these features for *all* occupations, it is possible to set aside a specific group as being unique in the extent to which they simultaneously possess these two features. In our first occupation grouping, listed in the first column of Table 2, we rely mostly on our own judgement in doing so, as it is difficult to find formal measures of the extent to which work output can be digitized[23] and – even more difficult – the extent to which work output is non-rival.

We also consider a more objective grouping of occupations, which we construct as follows. First, we collect information on the extent to which each U.S. industry's output is sold over the Internet[24] and, second, we identify the occupations that are both used most intensively and are most concentrated within those industries. For instance, within the industry "Software Publishing", Computer Software Developers are both a significant portion of total employment and, at the same time, are rarely employed outside that industry. Note that an alternative approach would simply focus on occupations within Internet-oriented industries. We instead focus only on occupations

[22]Rosen (1981) similarly discusses the close relationship between IRS at the occupation level and the "public good" nature of an occupation.

[23]There is a literature that attempts to capture whether the steps performed in the execution of an occupation are routine enough to be transmitted electronically. But note that this is not the same as measuring whether the occupation *output* can be transmitted electronically.

[24]We use data for 2012 from the U.S. Census E-Stats report: http://www.census.gov/econ/estats/, since the data is more complete for more recent years. The results are otherwise insensitive to the choice of year.

Table 1: **Occupation Groups**

Subjective ICT-Affected Occs	Objective ICT-Affected Occs	ICT-Unaffected Occs
Musicians	Financial Services Sales Agents	Postmasters
Designers	Other Financial Specialists	Mail and Paper Handlers
Athletes	Editors and Reporters	Postal Clerks
Photographers	Door-to-door sales and news vendors	Mail Carriers
Writers, Authors	Actors, Directors, Producers	Mail Clerks, outside post office
Actors, Directors, Producers	Broadcast Equipment Operator	Precision Makers, Repairers
Editors and Reporters	Advertising and Related Sales	Advertising Sales
Financial Services Sales Agents	Dressmakers and Seamstresses	Advertising Managers
Other Financial Specialists	Records Clerks	Architects
Computer Scientists	Retail Sales Clerks	Weighers, Measurers and Checkers
Announcers	Financial Managers	Supervisors of Vehicle Transport
Art-Entertainment Performers	Typesetters and Compositors	Truck, Delivery and Tractor Drivers
Technical Writers	Inspectors and Compliance Officers	Bus Drivers
Art Makers	Writers and Authors	Taxi Cab Drivers
Statisticians	Repairers of Data Process. Equipment	Parking Lot Attendants
Mathemeticians	Painting Machine Operators	Transport Equipment Operatives
Insurance Sales	Photographers	Operating Engineers
Buyers, Wholesale and Retail Trade	Accountants and Auditors	Crane, etc Operatives
Actuaries	Computers Software Developers	Excavating and Loading Operatives
Materials Engineers	Electrical Engineers	Misc. Material Moving Operatives

that are (mostly) specific to an industry because we want to ensure that the wage variation that we observe is due in large part to the effects of increased Internet access. In other words, when an occupation is used across many different industries its wage will be set in general equilibrium and will be influenced by (potentially non-Internet-related) shocks in all the industries.

Formally, we capture this notion with an "Internet-intensity-weighted" Herfindahl concentration measure for each occupation:

$$C_i = \sum_{j=1}^{J} (\xi_j s_{ij})^2 \tag{28}$$

where s_{ij} is the share of occupation i in industry j, $\sum_j s_{ij} = 1$, and ξ_j is the share of industry j's sales that are sold over the Internet. Clearly the measure C_i is highest for occupations that are highly concentrated in industries that sell extensively over the Internet.[25]

Table 1 lists the products most sold on the Internet, giving some sense of the types of products, and producers, that have most benefitted from the Internet. The left side of Table 2 lists our subjective choice of ICT-affected occupations and the center column lists the objective selection based on the exercise above.[26]

Finally, throughout the analysis we compare these ICT-affected occupations with another group

[25]In some cases the bulk of the profits due to industry sales accrue to managers and other indirect rights-holders whose occupations may be classified broadly (for instance, simply as "managers") and, as a result, the measure (28) will return a low value for these occupations due to their relatively equal distribution of employment across industries. This may be particularly relevant with respect to retail sales. Our measure is therefore more narrowly focused than the model allows. In short, our analysis highlights Musicians rather than CEOs.

[26]The occupations are drawn from the OCC1990 occupational classification.

that is virtually unaffected by new technologies such as the Internet. We define these unaffected occupations as those *least* affected by the Internet according to the objective measure described above. They occupy the right-most column in Table 2, from which one can see that there is little chance that ICT will have a significant impact on the production or sales of the services provided by these occupations. It is also clear that there is no obvious complementarity between the services provided by the affected occupations (objectively picked or subjectively picked) and those provided by the unaffected occupations, which motivates the empirical strategy suggested by (27). For each of our measures we also separately compare the top 10 and 20 occupations, in order to test the sensitivity of the results to the cutoff.

5.1. IRS, ICT and Wage Inequality

We first focus on the prediction of the model reflected in Propositions 3 and 4, namely that increases in the parameter B – which we interpret as innovation in the ICT sector and which, according to the model, will induce increases in the limit of IRS for ICT-affected occupations – will generate rising inequality across the talent distribution within these occupations, and a net gain in earnings for the most talented. Exploiting the one-to-one mapping of talent to wages in the model, we first focus on the wage distribution and compare the average annual change in the log wage at each percentile of the wage distribution for different occupation groups. As a first step, the log wage is "cleaned" of demographic and industry variation in a first-stage regression in order to focus as much as possible on wage variation that arises due to the intrinsic features of the occupations. In particular, to the extent that ICT technologies lead to greater IRS due to industry-specific features, rather than occupation features, we would like to remove this variation, and we do so by including industry fixed effects in the first stage. The residuals from this regression serve as the relevant wage variation going forward.

Descriptive Patterns

In Figure 8 we plot the distribution of log (residual) wage growth for the ICT-affected occupations[27] separately for two time periods: 1990 to 2000 and 2000 to 2010. We chose these dates as reflecting the (mostly) pre- and post- Internet periods, though clearly 1996 to 1999 saw initial growth in Internet access, as indicated in Figure 7.[28] In addition, the literature has found that the pre- and post-2000 periods exhibited very different patterns of wage growth[29], and our results can therefore

[27] Since the U.S. Census and ACS data are top-coded, we focus solely on the wage distribution up to the 99th percentile.

[28] The data available between 1990 and 2000 (from the Current Population Survey) contains too few observations for detailed, robust occupation-level analysis, motivating the use of decadal data.

[29] See, for instance, Autor and Dorn (2013) or Beaudry, Green and Sand (2013)

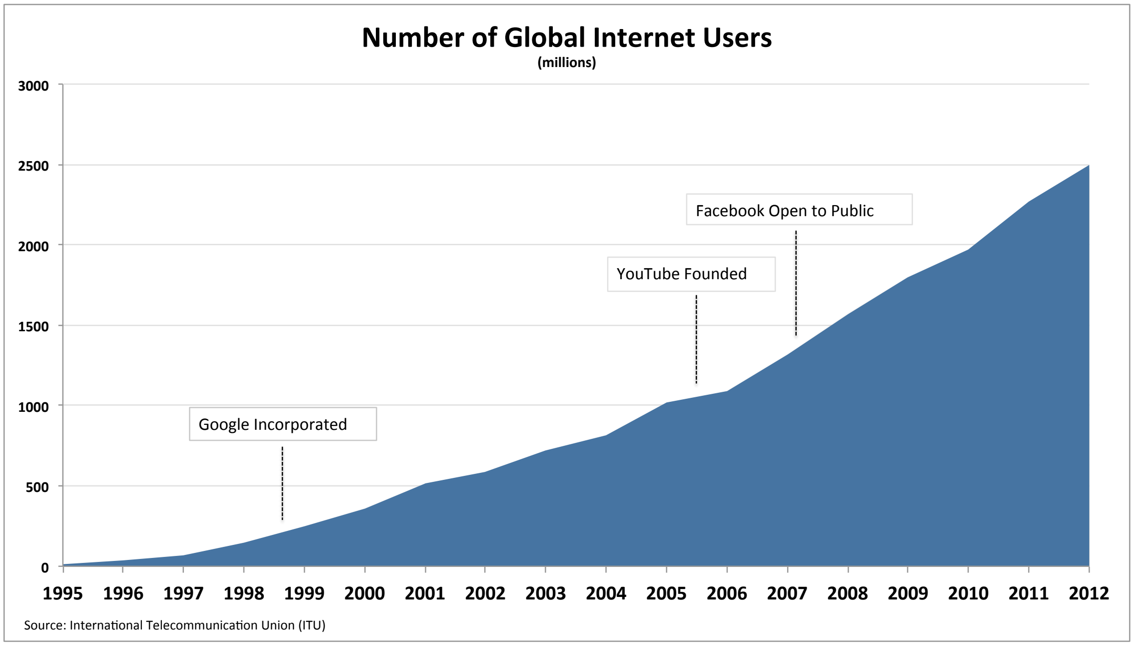

Figure 7: Growth in Global Internet Access

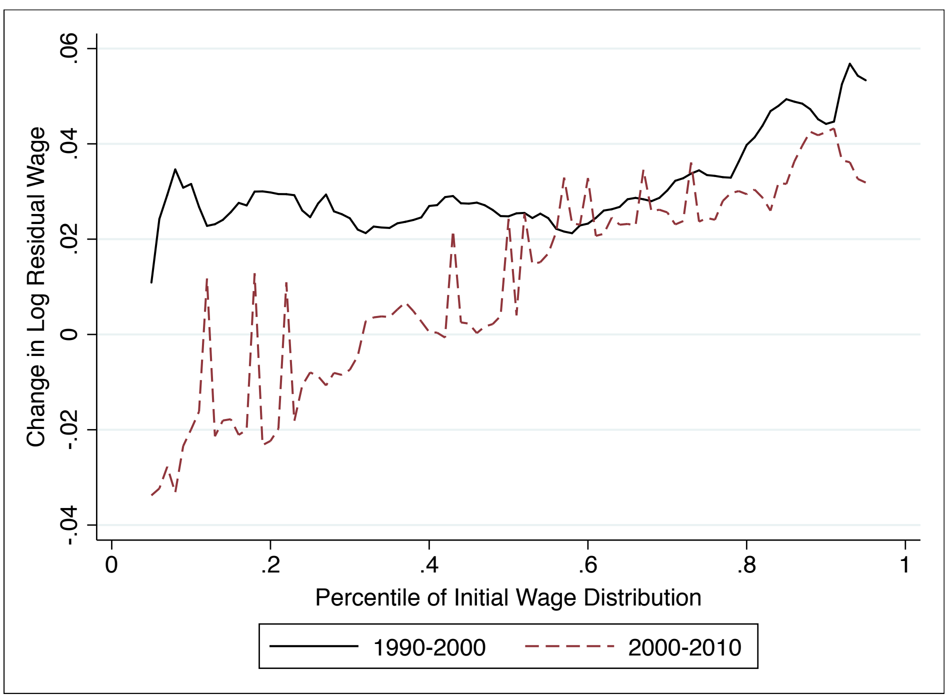

Figure 8: Growth in Log Residual Wage for ICT-Affected Occupations, 1990s vs 2000s

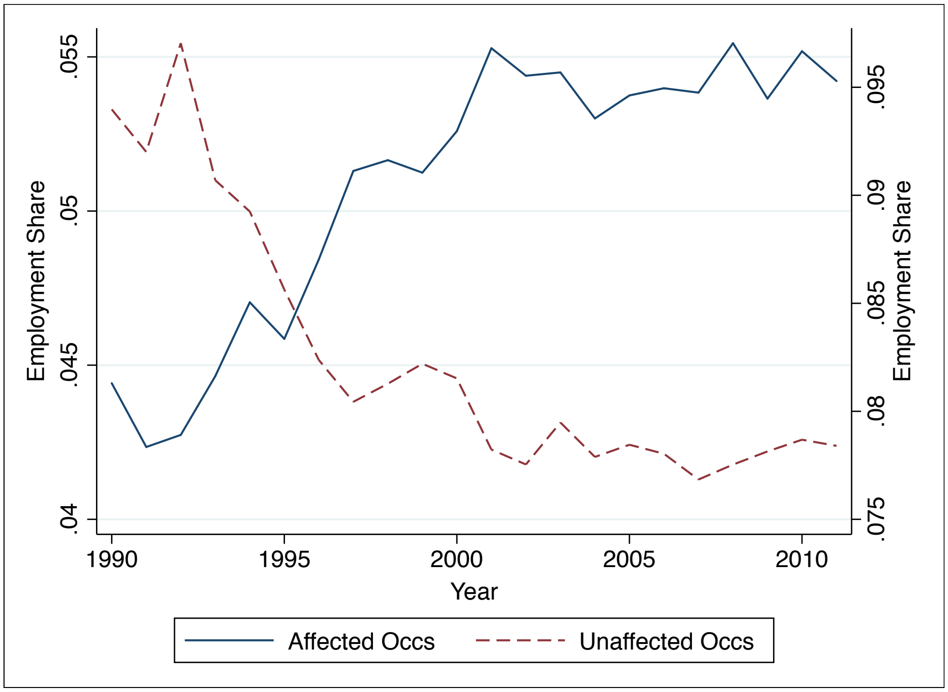

Figure 9: ICT-Affected vs ICT-Unaffected Occupations: Employment Share Trends, 1990-2000

be compared with these findings.

Figures 8 and 9 provide initial descriptive evidence in favor of the model's predictions. The pattern of wage growth presented in Figure 8 highlights the fact that the Internet period (post-2000) was associated with significant wage deterioration at the lower end of the wage distribution within ICT-affected occupations, a pattern that is not evident prior to that period and that is consistent with Proposition 3. The overall pattern is also one of monotonically rising returns across the wage distribution, consistent with Proposition 4, a pattern less evident in the pre-Internet period.

Figure 9 then plots the employment share of ICT-affected and ICT-unaffected occupations over the period 1990 to 2010. This pattern is mostly consistent with Proposition 2. In Figure 9 both occupation groups exhibit a break in the pattern of employment growth around 2000 that is consistent with the model predictions to the extent that other forces were present throughout the period. In other words, if non-ICT-related forces generated growth in employment for ICT-affected occupations during the 1990s *and* 2000s, the overall lack of growth in the 2000s could be explained by the mechanisms in our model, namely increased competition within ICT-affected occupations.

Regression Approach

Motivated by (27) and the discussion in Section 4.4, we can more formally estimate the break in the pattern of relative wage growth indicated by Figure 8 by estimating the following difference-in-

Table 2: Differential Within-Occ Inequality Growth: ICT-Affected Occs, 1990-2010

	Groups of 10 Occupations		Groups of 20 Occupations	
	(1) vs. Economy-Wide	(2) vs. Unaffected	(3) vs. Economy-Wide	(4) vs. Unaffected
		Subjective Group		
IRS×ICT	0.0358***	0.0301***	0.0450***	0.0657***
	(0.0007)	(0.0002)	(0.0007)	(0.0002)
Initial Wage Level	0.0159***	-0.0047	0.0160***	0.0076
	(0.0008)	(0.0068)	(0.0003)	(0.0066)
IRS×ICT×Init. Wage	0.0119**	0.0324**	0.0046	0.0129*
	(0.0027)	(0.0058)	(0.0020)	(0.0053)
Constant	-0.0131***	-0.0077***	-0.0146***	-0.0332***
	(0.0004)	(0.0001)	(0.0004)	(0.0001)
		Objective Group		
IRS×ICT	0.0072***	-0.0010**	0.0103***	0.0329***
	(0.0008)	(0.0002)	(0.0007)	(0.0004)
Initial Wage Level	0.0160***	0.0037	0.0157***	0.0121
	(0.0003)	(0.0157)	(0.0006)	(0.0111)
IRS×ICT×Init. Wage	0.0081***	0.0203	0.0122***	0.0157
	(0.0007)	(0.0151)	(0.0021)	(0.0094)
Constant	-0.0122***	-0.0022***	-0.0126***	-0.0314***
	(0.0004)	(0.0003)	(0.0004)	(0.0001)
Occ FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	67237	3938	67237	6564

Note: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

differences regression using the decadal Census and ACS data covering 1990 to 2000 and 2000 to 2010:

$$\triangle Wage_{qi,t:t-1} = c + \phi X_{qi,t-1} + \beta \left[IRS_i \times ICT_t \times Wage_{qi,t-1} \right] + \delta_i + \alpha_t + t_g + \epsilon_{qi,t-1} \qquad (29)$$

where in columns (1) and (3) of Table 3 IRS_i is an indicator equal to 1 if occupation i is classified as ICT-affected and 0 for all other occupations, ICT is an indicator equal to 1 for the post-2000 period and 0 in the pre-period, $Wage_{qi,t-1}$ is the log wage in an occupation and industry at wage percentile q in the initial period, δ_i and α_t are occupation and year fixed effects, t_g denotes occupation-group-specific trends, and $X_{qi,t-1}$ is a vector of controls that include the relevant set of interaction term and individual term controls required due to the triple interaction term – namely, $IRS_i \times ICT$, $ICT \times Wage_{qi,t-1}$, $IRS_i \times Wage_{qi,t-1}$, and $Wage_{qi,t-1}$ (the other individual terms are absorbed by the fixed effects). Finally, $\epsilon_{qi,t-1}$ is a disturbance term for which we assume $E[\epsilon_{qi,t-1}] = 0$. Note that the inclusion of occupation fixed effects and group trends implies that we focus narrowly on the differential inequality growth within occupations across the groups (affected vs. all other), conditional on the (potentially disparate) trends specific to each group over the entire period. In a second specification, presented in columns (2) and (4) of Table 2, we set IRS_i equal to 1 if occupation i is classified as ICT-affected and 0 for the ICT-unaffected occupations (setting aside all other occupations). In addition, we present the results for both the subjectively determined ICT-affected occupations (top half of Table 2), as well as the objective measure (bottom half of Table 2).

Continuing the discussion from Section 4.4, regression (29) allows us to focus narrowly on changes in wage inequality within occupations due to a rise in B – here reflected in increased Internet access. Importantly, under this specification any variation due to A should be differenced out, since the model finds that an increase in A influences both the affected and unaffected occupations in the same way. Also differenced out are any other sources of variation arising from outside the model that are common to both groups of occupations. In addition, by extending (27) to multiple periods, as we do in (29), the specification allows us to control for differential trends in wage inequality growth, originating prior to the Internet, across the "treatment" (i.e., affected) and "control" (i.e., unaffected) occupation groups, thus mitigating any bias caused by divergent trends. Given this research design, the sign of β is unambiguously predicted to be positive.

On the other hand, it is worth noting that this identification strategy leaves open the possibility that there are omitted variables that will bias our estimates of β. Most problematic are those that are both correlated with the intensity of Internet adoption across occupations while also directly increasing wage inequality in those occupations for reasons outside the model. In particular, the rapid fall in the price of computing technologies over the period, which were differentially adopted across industries and occupations while also facilitating access to the Internet, may have directly increased wage inequality within affected occupations, independent of any effect via access to the Internet. In this case, our estimates will be biased upward – i.e., we will over-estimate the differential impact of the Internet on our occupation groups. Furthermore, our use of the year 2000 as the threshold date may lead to bias due to effects that arise between 1995 (the "true" start date of the Internet) and 1999, biasing our estimates downward (though the inclusion of group trends may partially absorb this variation). In this case we may under-estimate the effect of the Internet. In light of this, we focus on the signs of coefficients and their statistical significance, which we believe are highly suggestive, while omitting discussion of the economic magnitudes associated with the coefficients.

We argued in Section 4.4 that β is expected to be positive when the mechanisms in our model are relevant. Indeed, the results provide fairly strong evidence that wage growth was greater at higher wage levels (percentiles) in the post-2000 period relative to the pre-2000 period for ICT-affected occupations. Specifically, each coefficient on the triple interaction term is positive, and five out of eight are statistically significant. This holds when they are compared with the set of occupations that are likely to be unaffected by new technologies (columns (2) and (4)) as well as when compared with all other occupations (columns (1) and (3)), suggesting that there is something specific to these occupations driving the wage pattern. In addition, the results hold when the ICT-affected occupations are classified subjectively or via the measure described above (top versus bottom of Table 2) and are robust to including more occupations in the group (columns (1) and (2) versus (3) and (4)).

Table 3 presents the results of a simpler difference-in-differences regression in which now employment growth is the dependent variable. To construct the employment growth measure we again "clean" the variation in log employment of demographic and industry-specific variation and then take the difference across periods. Formally, we estimate:

$$\triangle EmpGrowth_{i,t:t-1} = c + \psi IRS_i + \tau \left[IRS_i \times ICT_{t-1}\right] + \alpha_t + t_g + \epsilon_{i,t-1} \tag{30}$$

where the regressors are as described above. We again run the set of specifications reported in Table 2 in which the ICT-affected occupations are classified subjectively and objectively, are compared with all other occupations and narrowly with unaffected occupations, and finally we compare sets of 10 or 20 occupations. The estimates are negative, as the model predicts, in all cases except one, but are only significant when there are 20 occupations in the group and when compared to the most and least ICT-affected. Overall we take this as suggestive evidence that ICT-affected occupations shrunk relative to other occupations during the Internet period, relative to the pre-period, consistent with Proposition 2.

Table 3: Differential Employment Growth: ICT-Affected Occs, 1990-2010

	Groups of 10 Occupations		Groups of 20 Occupations	
	(1) vs. Economy Mean	(2) vs. Unaffected	(3) vs. Economy Mean	(4) vs. Unaffected
		Subjective Group		
IRS	-2.256	-15.94	-19.60	-30.69***
	(7.669)	(15.89)	(12.68)	(9.500)
IRS×ICT	-0.0359	-0.144	-0.110	-0.203***
	(0.0434)	(0.0979)	(0.0666)	(0.0607)
Constant	6.864***	-2.624	7.362***	-8.031**
	(0.194)	(7.405)	(0.953)	(3.471)
		Objective Group		
IRS	0.792	-19.26	-3.050	-18.93*
	(9.332)	(15.65)	(7.620)	(10.93)
IRS×ICT	0.0206	-0.126	-0.00627	-0.128*
	(0.0598)	(0.0972)	(0.0543)	(0.0665)
Constant	6.864***	-2.624	7.051***	2.303
	(0.292)	(6.925)	(0.274)	(5.609)
Year FE	Yes	Yes	Yes	Yes
Observations	7257	385	7257	664

Note: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

6. Concluding Remarks

We have developed a model incorporating two types of technological changes, and considered the consequences of each type for the income distribution and level of employment both across and within occupations. The model's mechanisms are unique in two primary ways. First, although type A technological change is unskilled-biased, it widens income inequality due to the fact that one of its main effects is to increase aggregate income, and a greater fraction of this increase is captured by agents with higher human capital endowments. This mechanism may be partly responsible for the growth in inequality that was coincident with rising average incomes during the late 1990s. Although this is usually attributed to Skill-Biased Technological Change, our results suggest a potential role for unskilled-biased technological change.

Second, type B technological change also raises income inequality, in this case via increased competition that drives workforce reallocation and redistributes revenue across practitioners within the affected occupations. We argue that *Increasing Returns to Scale up to some limit* are commonly present in occupations that require substantial human capital. When the limit up to which IRS operates increases for an occupation (for instance due to technological change), this generates two conflicting effects. On the one hand, the scale of operation for practitioners within the occupation increases, which benefits them. On the other hand, since this is true for all workers, they therefore face fiercer competition for their services. The latter effect is felt equally by all workers, but the benefits are greater for workers with higher human capital, who charge higher prices. The net effect is therefore to increase inequality within the occupation.

As far as we know, both mechanisms are new to the literature. In light of this, we test our model's predictions using U.S. data. We find patterns in the data consistent with the mechanisms we highlight, although we hesitate to place too much emphasis on findings that are not perfectly identified.

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Appendix A. Proof of Proposition 2

Proof. k is determined by equation (21). Differentiating with respect to B on both sides, we find

$$[d(\mu^{\frac{1}{1-\widehat{\rho}}} H_k^{\frac{\rho-\widehat{\rho}}{1-\widehat{\rho}}} h_k^{\frac{-\rho}{1-\widehat{\rho}}})/dk - (A/B+c)^{\frac{-\widehat{\rho}}{1-\widehat{\rho}}}] \cdot dk/dB = (k-1)d(A/B+c)^{\frac{-\widehat{\rho}}{1-\widehat{\rho}}}/dB + d[(1-k_0)(A/B+c)^{\frac{-\widehat{\rho}}{1-\widehat{\rho}}}]/dB$$

We further know that $d(^{\frac{1}{1-\widehat{\rho}}} H_k^{\frac{\rho-\widehat{\rho}}{1-\widehat{\rho}}} h_k^{\frac{-\rho}{1-\widehat{\rho}}})/dk < 0$ because $dH_k/dk < 0$ and $\frac{\rho-\widehat{\rho}}{1-\widehat{\rho}} > 0$, and $dh_k/dk > 0$. Therefore, on the LHS of the equation the term in front of dk/dB is negative.

On its RHS, $d(A/B+c)^{\frac{-\widehat{\rho}}{1-\widehat{\rho}}}/dB > 0$ and $k-1 < 0$. Therefore, if $d[(1-k_0)(A/B+c)^{\frac{-\widehat{\rho}}{1-\widehat{\rho}}}]/dB \leq 0$, which (as $k_0 = \frac{Bc}{A+Bc}$) is equivalent to $c \geq \frac{\widehat{\rho}}{1-\widehat{\rho}} \cdot \frac{A}{B}$, then the RHS is negative and thus $dk/dB > 0$. $\square$

Appendix B. Proof of Proposition 3

Proof. From (22), m_i increases with h_i^ρ. Therefore, to prove the proposition, it suffices to prove that dm_i/dB increases with h_i^ρ. By (22),

$$\frac{dm_i}{dB} = h_i^\rho / h_k^\rho \cdot [c - (A+Bc) \cdot \rho \cdot (\log h_k)' \cdot \frac{dk}{dB}] - c. \tag{B.1}$$

Only the first term depends on h_i. Therefore, dm_i/dB increases with h_i^ρ if and only if $c-(A+Bc) \cdot \rho \cdot (\log h_k)' \cdot \frac{dk}{dB} > 0 \Leftrightarrow$

$$c > (A+Bc) \cdot \rho \cdot (\log h_k)' \cdot \frac{dk}{dB}.$$

The identity of the marginal entertainer, k, is determined by equation (21). Taking the logarithm of both sides: $\frac{1}{1-\widehat{\rho}} \log \mu + \frac{\rho-\widehat{\rho}}{\rho(1-\widehat{\rho})} \log H_k^\rho - \frac{\rho}{1-\widehat{\rho}} \log h_k = \log(k-k_0) - \frac{\widehat{\rho}}{1-\widehat{\rho}} \log(A/B+c)$. Now taking the derivative with respect to B on both sides and noting that $\frac{dH_k^\rho}{dk} = -h_k^\rho$ and recalling $k_0 = \frac{Bc}{A+Bc}$: $[-\frac{\rho-\widehat{\rho}}{\rho(1-\widehat{\rho})} h_k^\rho / H_k^\rho - \frac{\rho}{1-\widehat{\rho}} (\log h_k)'] \cdot \frac{dk}{dB} = \frac{1}{k-k_0} \cdot [\frac{dk}{dB} - \frac{Ac}{(A+Bc)^2}] + \frac{\widehat{\rho}}{1-\widehat{\rho}} \cdot \frac{A}{(A+Bc)B} \Rightarrow$

$$\frac{dk}{dB} = \frac{1/(k-k_0) \cdot Ac/(A+Bc)^2 - \widehat{\rho}/(1-\widehat{\rho}) \cdot A/[A+Bc)B]}{1/(k-k_0) + \frac{\rho}{1-\widehat{\rho}} (\log h_k)' + \frac{\rho-\widehat{\rho}}{\rho(1-\widehat{\rho})} h_k^\rho / H_k^\rho}.$$

The numerator is smaller than $1/(k-k_0) \cdot Ac/(A+Bc)^2$, while the denominator is greater than $1/(k-k_0) + \frac{\rho}{1-\widehat{\rho}} (\log h_k)'$, which is in turn greater than $1/(k-k_0) + \rho(\log h_k)'$. Therefore,

$$\frac{dk}{dB} < \frac{Ac/(A+Bc)^2}{1+\rho(\log h_k)'(k-k_0)}.$$

With this inequality, the inequality (B.2) follows from $c > (A+Bc) \cdot \rho \cdot (\log h_k)' \cdot \frac{Ac/(A+Bc)^2}{1+\rho(\log h_k)'(k-k_0)}$, which, with rearrangement and noting that $k_0 = \frac{Bc}{A+Bc}$, is equivalent to:

$$\frac{\rho \cdot h'_k/h_k}{1+\rho \cdot h'_k/h_k \cdot (k-k_0)} < \frac{1}{1-k_0}.$$

Note the LHS of the inequality increases with ρ and $\rho \leq 1$. The inequality, therefore, follows from

$$\frac{h'_k/h_k}{1+h'_k/h_k \cdot (k-k_0)} < \frac{1}{1-k_0},$$

which follows from assumption (11) as $k > k_0$. □

Appendix C. An Example in which dm_i/dB Decreases with m_i

Following the proof of Proposition 3, dm_i/dB decreases with m_i if

$$c < (A+Bc) \cdot \rho \cdot (\log h_k)' \cdot \frac{dk}{dB}. \tag{C.1}$$

To construct such an example, we therefore want $(\log h_k)'$ to be large enough. Here is one example. Let $\widehat{\rho} = 0$ and let the distribution of human capital be given by

$$h_i = \left\{ \begin{array}{c} x \text{ if } i < k - \epsilon/2 \\ x + \frac{\delta}{\epsilon}(i - k + \epsilon/2) \text{ if } k - \epsilon/2 \leq i \leq k + \epsilon/2 \\ x + \delta \text{ if } k + \epsilon/2 < i \end{array} \right\}$$

for some $\epsilon, \delta, k > 0$ and $k - \epsilon/2 > 0$ and $k + \epsilon/2 < 1$. Therefore, $h'_k = \frac{\delta}{\epsilon}$ and $h'_k/h_k \to \infty$ if $\epsilon \to 0$. For the time being, k is just a parameter. But this parameter identifies the marginal agent in equilibrium if it satisfies equation (21), which, since $\widehat{\rho} = 0$, becomes

$$\mu H_k^\rho h_k^{-\rho} = k - k_0. \tag{C.2}$$

With $\epsilon \to 0$, the LHS of this equation approaches $\mu \frac{(x+\delta)^\rho (1-k)}{(x+\delta/2)^\rho}$. Thus, with $\epsilon \to 0$, k approaches the root of

$$\mu \frac{(x+\delta)^\rho}{(x+\delta/2)^\rho}(1-k) = k - k_0,$$

denoted by $\widetilde{k}$. Clearly, $\widetilde{k} < 1$.

By (B.2), with $\widehat{\rho} = 0$ and some rearrangement

$$\frac{dk}{dB} = \frac{Ac/(A+Bc)^2}{1+\rho(\log h_k)' \cdot (k-k_0) + h_k^\rho/H_k^\rho \cdot (k-k_0)}. \tag{C.3}$$

From (C.2) it follows that $h_k^\rho / H_k^\rho \cdot (k - k_0) = \mu$. Substituting this into (C.3),

$$\frac{dk}{dB} = \frac{Ac/(A+Bc)^2}{1 + \mu + \rho(\log h_k)' \cdot (k - k_0)}.$$

Then, (C.1) is equivalent to

$$\frac{1}{1-k_0} < \frac{\rho \cdot (\log h_k)'}{1 + \mu + \rho(\log h_k)' \cdot (k - k_0)}, \tag{C.4}$$

where we also apply $1 - k_0 = \frac{A}{A+Bc}$. Note that for the RHS of this inequality, if $\epsilon \to 0$, $(\log h_k)' \to \infty$ and $k \to \widetilde{k} < 1$, and then the RHS approaches $\frac{1}{\widetilde{k} - k_0} > \frac{1}{1-k_0}$, the LHS. Therefore, if ϵ is close enough to 0, inequality (C.4), and thus inequality (C.1), holds true, which means that dm_i/dB decreases with m_i.

Appendix D. Proof of Lemma 1

Proof. By (B.1), $\frac{dm_i}{dB} > 0$ if

$$h_i^\rho / h_k^\rho \cdot [c - (A + Bc) \cdot \rho \cdot (\log h_k)' \cdot \frac{dk}{dB}] > c. \tag{D.1}$$

With an upper bound of $\frac{dk}{dB}$ given by (B.2), this inequality follows from: $h_i^\rho / h_k^\rho \cdot [c - (A + Bc) \cdot \rho \cdot (\log h_k)' \cdot \frac{Ac/(A+Bc)^2}{1+\rho(\log h_k)'(k-k_0)}] > c \Leftrightarrow$

$$h_i^\rho / h_k^\rho \cdot [1 - \frac{A}{A+Bc} \cdot \frac{\rho \cdot (\log h_k)'}{1 + \rho(\log h_k)'(k - k_0)}] > 1, \tag{D.2}$$

which is equivalent to (24). $\square$

Appendix E. Proof of Lemma 2

Proof. We prove the lemma in three steps.

Step 1: If $h_1 > 1$, then

$$k - k_0 < D(\frac{h_1}{h_k})^{\frac{\rho}{1-\widehat{\rho}}} (1-k)^{\frac{\rho - \widehat{\rho}}{\rho(1-\widehat{\rho})}}. \tag{E.1}$$

Proof: k is determined by equation (21), or equivalently, $k - k_0 = DH_k^{\frac{\rho-\widehat{\rho}}{1-\widehat{\rho}}} h_k^{\frac{-\rho}{1-\widehat{\rho}}}$. Note that $H_k = \{\int_k^1 h_i^\rho\}^{\frac{1}{\rho}}|_{h_i'>0} < \{\int_k^1 h_1^\rho\}^{\frac{1}{\rho}} = h_1(1-k)^{\frac{1}{\rho}}$. Therefore, $H_k^{\frac{\rho-\widehat{\rho}}{1-\widehat{\rho}}} h_k^{\frac{-\rho}{1-\widehat{\rho}}} = (\frac{H_k^{\rho-\widehat{\rho}}}{h_k^\rho})^{\frac{1}{1-\widehat{\rho}}} < (\frac{h_1^{\rho-\widehat{\rho}}(1-k)^{\frac{\rho-\widehat{\rho}}{\rho}}}{h_k^\rho})^{\frac{1}{1-\widehat{\rho}}} = h_1^{\frac{\rho-\widehat{\rho}}{1-\widehat{\rho}}} / h_k^{\frac{\rho}{1-\widehat{\rho}}} \cdot (1-k)^{\frac{\rho-\widehat{\rho}}{\rho(1-\widehat{\rho})}}|_{\frac{\rho-\widehat{\rho}}{1-\widehat{\rho}} \le \frac{\rho}{1-\widehat{\rho}} \text{ and } h_1>1} < h_1^{\frac{\rho}{1-\widehat{\rho}}} / h_k^{\frac{\rho}{1-\widehat{\rho}}} \cdot (1-k)^{\frac{\rho-\widehat{\rho}}{\rho(1-\widehat{\rho})}}$, which implies (E.1).

Step 2:

$$k < f(k_0, D \cdot (\frac{h_1}{h_k})^{\frac{\rho}{1-\widehat{\rho}}}). \tag{E.2}$$

Proof: Let $\tau := f(k_0, D \cdot (\frac{h_1}{h_k})^{\frac{\rho}{1-\widehat{\rho}}})$. By the definition of $f(\cdot,\cdot)$, $\tau - k_0 = D \cdot (\frac{h_1}{h_k})^{\frac{\rho}{1-\widehat{\rho}}} \cdot (1-\tau)^{\frac{\rho-\widehat{\rho}}{\rho(1-\widehat{\rho})}}$. The two sides of this inequality minus, respectively, the two sides of inequality (E.1) leads to $\tau - k > D(\frac{h_1}{h_k})^{\frac{\rho}{1-\widehat{\rho}}}[(1-\tau)^{\frac{\rho-\widehat{\rho}}{\rho(1-\widehat{\rho})}} - (1-k)^{\frac{\rho-\widehat{\rho}}{\rho(1-\widehat{\rho})}}]$. This inequality can hold true only if $\tau > k$: if $\tau \leq k$, then the LHS of the inequality is negative, while the RHS is positive – and thus cannot be strictly smaller than the LHS – because $1 - \tau \geq 1 - k$, which implies $(1-\tau)^{\frac{\rho-\widehat{\rho}}{\rho(1-\widehat{\rho})}} - (1-k)^{\frac{\rho-\widehat{\rho}}{\rho(1-\widehat{\rho})}} \geq 0$ (as $\frac{\rho-\widehat{\rho}}{\rho(1-\widehat{\rho})} > 0$). Q.E.D.

Step 3: We prove the Lemma by showing that $\zeta \geq h_1/h_k$ leads to a contradiction. Clearly, $f(k_0, y)$ increases with y, and therefore if $\zeta \geq h_1/h_k$, then $f(k_0, D\cdot(\frac{h_1}{h_k})^{\frac{\rho}{1-\widehat{\rho}}}) < (f(k_0, D\cdot\zeta^{\frac{\rho}{1-\widehat{\rho}}})$, which together with (E.2) implies that $k < f(k_0, D \cdot \zeta^{\frac{\rho}{1-\widehat{\rho}}})$. Since $h'(i) > 0$, then $h_k < h(\ f(k_0, D \cdot \zeta^{\frac{\rho}{1-\widehat{\rho}}}))$. Thus we have

$$\zeta \geq \frac{h_1}{h_k} > \frac{h_1}{h(f(k_0, D \cdot \zeta^{\frac{\rho}{1-\widehat{\rho}}}))},$$

which implies $\zeta \cdot h(f(k_0, D \cdot \zeta^{\frac{\rho}{1-\widehat{\rho}}})) > h_1$, in contradiction to the lemma. Q.E.D. $\square$

Appendix F. Proof of Proposition 5

Proof. k is determined by equation (21). Differentiate with respect to A on both sides, and we find

$$[d(\mu^{\frac{1}{1-\widehat{\rho}}} H_k^{\frac{\rho-\widehat{\rho}}{1-\widehat{\rho}}} h_k^{\frac{-\rho}{1-\widehat{\rho}}})/dk - (A/B+c)^{\frac{-\widehat{\rho}}{1-\widehat{\rho}}}] \cdot dk/dA = (k-1)d(A/B+c)^{\frac{-\widehat{\rho}}{1-\widehat{\rho}}}/dA + d[(1-k_0)(A/B+c)^{\frac{-\widehat{\rho}}{1-\widehat{\rho}}}]/dA$$

We saw $d(^{\frac{1}{1-\widehat{\rho}}} H_k^{\frac{\rho-\widehat{\rho}}{1-\widehat{\rho}}} h_k^{\frac{-\rho}{1-\widehat{\rho}}})/dk < 0$ because $dH_k/dk < 0$ and $\frac{\rho-\widehat{\rho}}{1-\widehat{\rho}} > 0$, and $dh_k/dk > 0$. Therefore, on the LHS of the equation the term in front of dk/dA is negative.

On its RHS, $d(A/B+c)^{\frac{-\widehat{\rho}}{1-\widehat{\rho}}}/dA < 0$ and $k-1 < 0$. Therefore, if $d[(1-k_0)(A/B+c)^{\frac{-\widehat{\rho}}{1-\widehat{\rho}}}]/dA \geq 0$, which (as $k_0 = \frac{Bc}{A+Bc}$) is equivalent to $c \geq \frac{\widehat{\rho}}{1-\widehat{\rho}} \cdot \frac{A}{B}$, then the RHS is positive and thus $dk/dA < 0$. $\square$