Will information technology lead to a winner-takes-all society?

Gilles Saint-Paul*
GREMAQ-IDEI,
Université des Sciences Sociales de Toulouse,
Universitat Pompeu Fabra,
CEPR and IZA

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1. Introduction

What is the contribution of new information technology to the evolution of income distribution? Can it explain the trend increase in inequality over the last two decades and the fall in the wages of the least skilled? These are the questions this paper is aimed at.

The standard view about information technology is that computers are substitute for unskilled workers, so that their introduction is quite similar to a rise in the supply of unskilled workers or trade with a country abundantly endowed in that factor.[1]

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[1] For the literature on inequality and the role of technology and trade, see Bound and Johnson

The kind of effects we analyze here are quite different. Information technology allows the best people to spread their talent over an ever larger share of the market, at the expense of less able workers who may find themselves displaced into low-paying jobs. Through television, compact disks, radio, consumers get access to the best performers so that being even marginally less good is of no use. Actors or singer who once competed for excellence at the city level now have to be the best nationwide in order to survive, because TV makes the best actor available to all. This trend toward a society where all the rewards go to the best has been analyzed in Frank and Cook's best-seller *The winner takes-all society* (1995).[2]

Is that trend relevant to understanding what's happening in the bulk of the labor market or are we just talking about football players and divas? For some authors such as Rosen, (1997), these phenomena are likely to have a small aggregate impact, because they are limited to markets where replication is costless such as the media, or to markets where ranking enters the definition of the good being consumed, such as competition in sports.

Yet we believe that information technology is now so pervasive that it has to affect most workers, even though it may not show up with effects as drastic as the ones observed in the markets for superstars. The ideas and behaviour of the most able people are now much easier to duplicate than in the past, and ideas and communication play an increasing role in corporations.

One may think of wages as the return to two types of human capital. One is productivity, a sheer quantitative measure of how many goods or services one can produce; the other is the ability to produce ideas that may be costlessly replicated

(1992), DiNardo and Pischke (1996), Juhn, Murphy and Pierce, (1991), Katz and Murphy (1992), Krueger (1993), Lawrence and Slaughter (1993) and Levy and Murnane (1992).

[2] The role of superstars was studied by Rosen (1981), while endogenous stratification arises in the context of the models by Becker (1973), Kremer (1993), and Rioux (1999).

over a segment of the economy. The latter is the only thing that matters for superstars and "symbol producers". But it is probably a dimension of skill that is rewarded for most workers. Progress in information technology has increased the reward to that dimension which may to some extent account for the rise in inequality within and between educational groups.

To analyze this issue we develop a model where workers have two skills, "productivity" and "creativity". Productivity is the number of units of output generated by the worker's effort on the job, while creativity describes the distribution of ideas that the worker will have. More creative people are more likely to have better ideas. A worker's idea can be applied over a network of communication to improve production. Ideas are not cumulable, so that only the best idea within a given network will be applied. While the essence of ideas is that they generate an external effect on the network, we assume that part of this externality is appropriable by firms; indeed, we assume that firms and networks coincide, so that all the beneficial effect of an idea will show up in increased profits.[3] Ex-ante, this translates into greater wages for more creative workers. The model makes it possible to discuss the impact of an improvement in information technology, which we model as an increase in the size of networks. We then discuss how workers will be allocated to firms in equilibrium and how network size affects the distribution of income.

Our results are much more optimistic than the aristocratic nightmare depicted in Frank and Cook's book. We do find that larger networks increase the return to creativity and inequality over some range. To the extent that creativity is not fully observable, but is positively correlated with measured skilled, this rise in inequality may be observed both within and across skill groups. It is due to what we call the burden effect: less creative people have to "pay" for the negative externality they exert on the network's best idea by accepting wages lower than

[3] This can be rationalized using a Coasian argument, see Coase (1995).

their marginal product. But we show that there are strong countervailing effects. First, the best idea generates positive spillovers over all workers in the network (the spillover effects); second, as network size increases, there will be more good ideas available within the network, which makes less creative people less of a burden and more creative people less precious. As a result, we show that as network size goes on increasing, inequality eventually falls, and that the wages of the least skilled can never fall in absolute terms in response to an increase in network size.

2. Setup of the model

The economy is populated by workers who differ in their skills. Each agent is endowed with a vector of skills $x = (h, y) \in H$. The first component of that vector, h, represents the worker's ability to have ideas that can be spread over the network and be used to reduce production costs. We call it 'creativity'. The second component, y, is the worker's physical productivity. The total mass of workers is normalized to 1, and we shall restrict ourselves to the case where productivity and creativity are perfectly correlated, i.e. $h = ay + b$.

The economy is made of firms called *networks.* Each network hires a mass s of workers. s is the size of the network and one of the main parameters of interest. It represents the range over which ideas can be spread at no cost. Improvements in information technology are therefore associated with an increase in s: the larger the network, the larger the number of workers who can benefit from a given idea. To avoid integer problems, we consider that there is a continuum of networks. Under full employment there is therefore a mass of $1/s$ networks operating. We index them by $n \in [0, 1/s]$. Each network n can be represented by a mapping from $[0, s]$ to $H : i \to (h_{in}, y_{in})$, which describes the creativity and productivity of each worker of the network, indexed by $i \in [0, s]$.

The timing of events is as follows:

1. Firms freely enter the market.

2. The labor market operates and hiring takes place. Firm maximize their expected profit. This yields an equilibrium wage schedule $w(y)$. Note that wages are set prior to production.

3. A finite number N of randomly drawn workers have an idea. Each firm makes use of its workers' ideas to improve production. Production takes place and wages are paid. We assume that N is large, so that each firm considers that a number $n = sN$ of its employees will have ideas.

We now describe the idea process and the production process. There are two possible ideas, a good one (G) and a bad one (B). The probability of any worker having a bad idea is P^h, where $0 < P < 1$ and h is the worker's creativity. The probability of having a bad idea is clearly decreasing with creativity.

Then, if an idea $z \in \{B, G\}$ is applied to a given network, total output in that network is given by:

$$u(z) \int_0^s y_{in} di = u(z) s \bar{y}_n,$$

where $u(G) > u(B)$ is an increasing function of z and $\bar{y}_n$ is the average productivity of network n's workers. Thus the production function is linear in individual productivity, while any employee's idea can be applied by all workers in the network, so that it acts as a multiplicative shift to the production function.

We assume that ideas are not cumulative, that is any network will apply the best idea among its employees. This is the winner-takes-all aspect of the labor market. An idea is useless even if it is only marginally worse than another one that can be applied over the same network, while productivities add up so that if a worker's productivity is marginally lower than another's, so are their marginal products.

The probability that the best idea is not applied is then, conditional on the set of workers who have ideas:

$$\Phi\{h_i\} = \prod_{i=1}^{n} P^{h_i} = P^{\sum_{i=1}^{n} h_i} \tag{1}$$

Given that the h_i's are randomly drawn, expected output is given by:

$$\begin{aligned} E_n(Y) &= P^{sN\bar{h}_n}\left[u(B)-u(G)\right]s\bar{y}_n + u(G)s\bar{y}_n \\ &= \phi(\bar{h}_n, \bar{y}_n) \end{aligned}$$

where $\bar{h}_n$ is the firm's average creativity and $\bar{y}_n$ its average productivity. ϕ is increasing in both its arguments, concave in the first one and linear in the second one.

An equilibrium tells us, for each firm indexed by $n \in [0, 1/s]$, what is the set of workers that it employs. It also tells us how wages depend on worker characteristics. This is given by the wage schedule $w(h, y)$. It must satisfy the free entry, or zero profit condition, which can be written as

$$\begin{aligned} \forall\, n &\in [0, 1/s]\,,\ \phi(\bar{h}_n, \bar{y}_n) = \int_0^s w(h_{in}, y_{in})di, \\ \text{where } \bar{h}_n &= \left(\int_0^s h_{in}di\right)/s \text{ and } \bar{y}_n = \left(\int_0^s y_{in}di\right)/s \end{aligned}$$

Firms must also determine their composition optimally, i.e. hiring any other set of workers cannot yield positive profits:

$$\phi(\tilde{h}_n, \tilde{y}_n) \leq \int_0^s w(\hat{h}_{in}, \hat{y}_{in})di,$$

where $(\hat{h}_{in}, \hat{y}_{in})$ is any alternative, feasible choice of the set of workers for firm n and $\tilde{h}_n, \tilde{y}_n$ the corresponding mean levels of productivity and creativity.

Finally, in equilibrium it must be that there is full employment for any type of worker, i.e. the distribution of (h, y) implied by the assignment of workers matches the actual one.

3. Properties of the wage schedule

Because of the spillovers exerted by workers on other workers of the same networks through the ideas they have, a firm's production function is not concave.

Therefore a worker's income cannot be equal to the sum of the marginal product of his creativity and his productivity. In Saint-Paul (2001), we have derived some properties of equilibrium for a more general class of models. There, it is proved that given the assignment of workers to firms, the wage schedule is the upper envelope of a set of linear functions representing each firm's willingness to pay for any worker type. That is:

$$w(h, y) = \max_n \left[\phi_2'(\bar{h}_n, \bar{y}_n)y + \phi_1'(\bar{h}_n, \bar{y}_n)(h - \bar{h}_n)\right]/s \quad (2)$$

In equilibrium any worker type works in the firm which has the greatest willingness to pay for that type. Since $w(.,.)$ is the maximum of a set of linear functions, the wage schedule must necessarily be convex.

There are two ways to interpret (2).

First, wages can be decomposed as the sum of two terms; the first term $\phi_2'(\bar{h}_n, \bar{y}_n)y/s$ is the worker's return to his productivity, which is simply equal to his physical product in his firm ignoring his intellectual contributions. The second term $\phi_1'(\bar{h}_n, \bar{y}_n)(h - \bar{h}_n)/s$ is a "bonus" paid for creativity. Because of the zero profit condition this bonus has to average to zero, and we can see that it is proportional to the *deviation* between this individual's creativity and average creativity in the firm. Thus people earn more (less) than their marginal product depending on whether they are more (less) creative than their firm's average. This way, low creativity people are penalized for the fact that they occupy a job that might be instead held by somebody equally productive but with better ideas. Hence, the wage structure rewards *absolute* productivity, but *relative* creativity, where the basis of comparison is average creativity in the same network.

Alternatively, one could decompose wages into three terms. The first term is still $\phi_2'(\bar{h}_n, \bar{y}_n)y/s$, the marginal return to productivity; the second term is $\phi_1'(\bar{h}_n, \bar{y}_n)h/s$, the marginal return to creativity, and the last (deducted) term is $\phi_1'(\bar{h}_n, \bar{y}_n)\bar{h}_n/s$, the market price that an individual has to pay for joining network

n. This price is higher, the more the network's average productivity, while the dependence in creativity is ambiguous.

This formula also implies that the return to productivity is higher in more creative firms ($\phi_2'(\bar{h}_n, \bar{y}_n)$ is increasing in $\bar{h}_n$), while the return to relative creativity is higher in more productive firms and lower in more creative firms ($\phi_1'(\bar{h}_n, \bar{y}_n)$ is increasing in $\bar{y}_n$ and decreasing in $\bar{h}_n$). This is because high creativity increases everybody's marginal product but reduces the value of individual creativity to the firm as others' ideas are already quite good, and because more productive firms get the most out of good ideas since these act as an output multiplier.

4. The structure of equilibria

Let us now make use of the assumption that h and y are linearly correlated. The firm's total output can then be expressed as a sole function of its average productivity level:

$$\begin{aligned}\phi(\bar{h}_n, \bar{y}_n) &= P^{sN(a\bar{y}_n+b)}\left[u(B) - u(G)\right] s\bar{y}_n + u(G)s\bar{y}_n \\ &= \psi(\bar{y}_n)\end{aligned}$$

The right hand side of (2) can be rewritten as

$$\left[\psi'(\bar{y}_n)(y - \bar{y}_n) + \psi(\bar{y}_n)\right]/s \qquad (3)$$

That is, if we define the average output schedule as relating a firm's average output to its average productivity, the wage schedule offered by firm n to workers of type y is given by the straight line tangent to the average output schedule at $\bar{y}_n$. This simple property allows us to easily characterize equilibria.

It is easy to see that the second derivative of the average output schedule, ψ''/s, is has the same sign as

$$2 + asN \ln P\bar{y}_n$$

Assume $a > 0$, i.e. that productivity and creativity are positively correlated, and let y be distributed over $[y_{\min}, y_{\max}]$. Then we can distinguish three cases:

1. If $s < \frac{2}{aN|\ln P|y_{\max}}$, then the average output schedule is convex throughout (Figure 1). A firm's willingness to pay line is always below the average output schedule, implying that for any type y other than its average productivity level it is less willing to pay than an entrant that would only hire workers of type y. Consequently, the equilibrium must be such that firms only employ one type of labor. We call such an equilibrium "hypersegregated". The wage schedule then coincides with the average output schedule.

2. If $s > \frac{2}{aN|\ln P|y_{\min}}$, then the average output schedule is concave throughout (Figure 2). In that case, there cannot be more than one type of firm in equilibrium, otherwise workers would be allocated across firms in a way inconsistent with these firm's average productivity level. For example, if there are two firms as in Figure 3, firm I only recruits workers more productive than its average level, while the converse occurs to firm II. This is clearly impossiblė. Consequently, all firms have the same average productivity level, which, for equilibrium to hold, must be equal to the economy's average productivity level. The wage schedule is linear and tangent to the average output schedule at a point corresponding to the economy's average productivity level.

3. If $\frac{2}{aN|\ln P|y_{\max}} < s < \frac{2}{aN|\ln P|y_{\min}}$, then the average output schedule is convex and then concave (Figure 4a,b). In that case, either there exists a unique type of firm whose average productivity equals that of the economy (Figure 4a), or there exist a hypersegregated zone of low-productivity, low wage firms only hiring one type of labor, which employs workers less productive than some threshold level y^*, and a "unitary" zone of firms whose average productivity level is equal to the population average over $[y^*, y_{\max}]$, and who employ workers of different skills so that together, they exhaust the supply of labor in that interval.

5. Impact of network size on the distribution of income

We are now in a position to study how an improvement in information technology, which we model as an increase in network size, affects the distribution of income.

A natural measure of inequality is simply the slope of the wage schedule, which according to (3) is simply given by $\psi'(\bar{y}_n)/s$, where $\bar{y}_n$ is the average productivity of firms who hire workers of type y. For example, in case 1 above, it is simply equal to y, while in case 2 it is equal to the economy's average productivity level.

Computing $\psi'(\bar{y}_n)/s$ and then its derivative with respect to s we can see that it has the same sign as:

$$(2a\bar{y}_n + b) + sNa\bar{y}\ln P,$$

which, given that $\ln P < 0$, is positive and then negative as s increases. Thus, improvements in information technology first increase inequality for s small but past a certain value of s they reduce it.

Hence, contrary to some conventional wisdom, improvement in information technology does not necessarily increase inequality. This is only so below a certain level of technology and skills.

This nonmonotonicity is the result of conflicting effects. On the one hand, the most creative workers can spread their ideas over a larger network of economic activity when s increases. This tends to increase their wages relative to others. On the other hand, when networks get larger, the ideas of a given, highly creative worker, are less valuable because it is more likely that somebody else in the network would have had an idea almost as good. That is, past some large network sizes superstars end up competing against each other which eventually pushes down their wages relative to other workers.

6. The role of international trade

Although the recent empirical literature on the rise in inequality does not ascribe a big role to foreign trade, it is interesting to discuss how "globalization" may affect the distribution of income in our model.

This economy has a continuum of skill levels and only one good. Therefore, as long as labor is not mobile, international trade should not affect the distribution of income. However, things are different if ideas, in addition to goods, are mobile, that is, if information technology allows ideas to spread across borders. A multinational network can then take advantage of cross-country differences in relative wages to structure its workforce optimally. A country's distribution of income will then be determined by the world distribution of skills. What happens, then, if a high-skill country trades with a low-skill one? It is as if the distribution of skills in both countries suddenly became equal to the world's distribution of skills. To maintain equality between supply and demand, some multinational networks, that have the same skill composition of similar national networks, will arise. So, in the high-skill country, it is as if there was a reduction in the quality of the workforce.

Overall, the effects are qualitatively similar to the ones predicted by the Stolper-Samuelson theorem, with two important provisos. First, the crucial mechanism is the mobility of ideas, rather than goods. Second, openness affects the pattern of segregation, and workers who remain in a hypersegregated zone are not affected by the change.

Finally, note that here "globalization" affects the distribution of income despite having no effects on relative prices, since there is only one good. This may lead to a reconsideration of the role of international trade in inequality, since it was dismissed empirically precisely because the rise in inequality was not associated with adequate movements in relative prices.[4]

[4] See Lawrence and Slaughter (1993).

7. Conclusion

Our analysis should perhaps lead to pouring some cold water over the view that information technology may be harmful for the distribution of income. It is true that they make wages depend on one's standing relative to peers, and that inequality may increase both within groups and between groups. But we have seen that there are strong spillover effects that guarantee that inequality eventually falls when network size get large, and that the wages of the least paid never fall in response to an increase in network size.

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Figure 1: the convex case

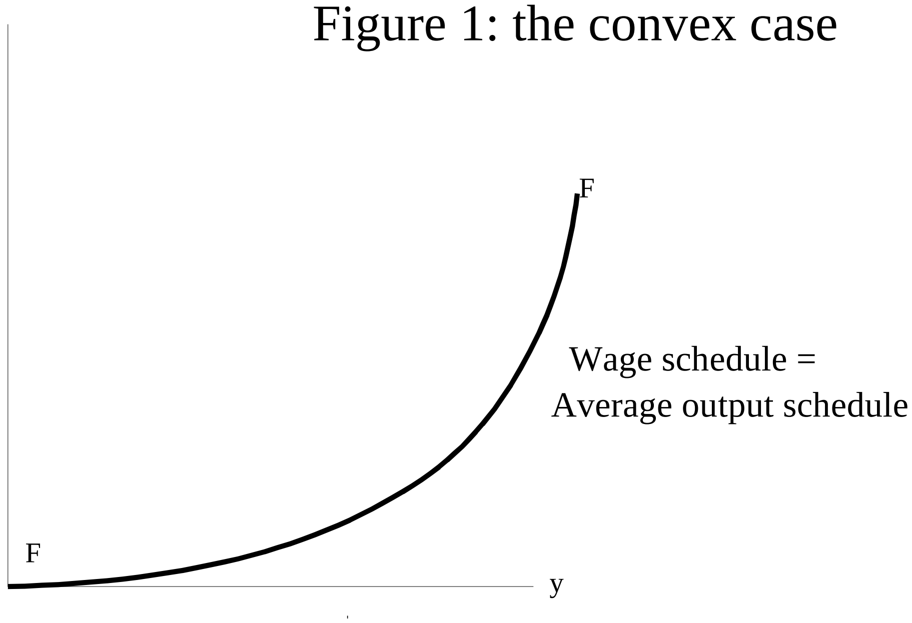

Figure 2: the concave case

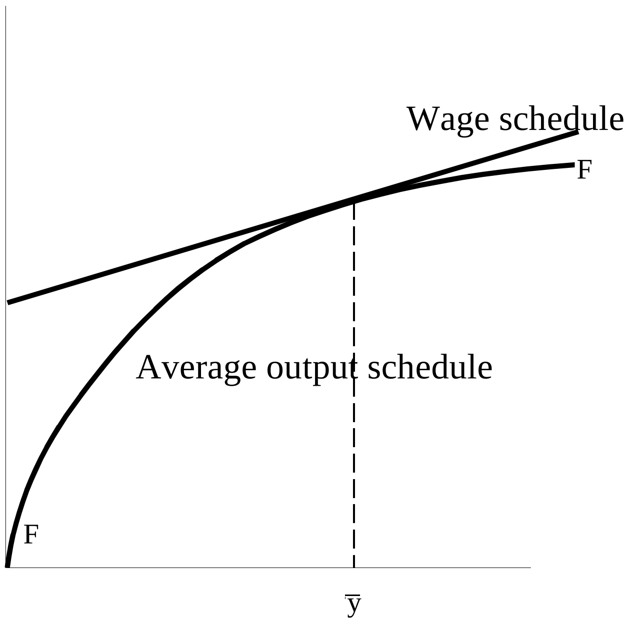

Figure 3: an impossible situation

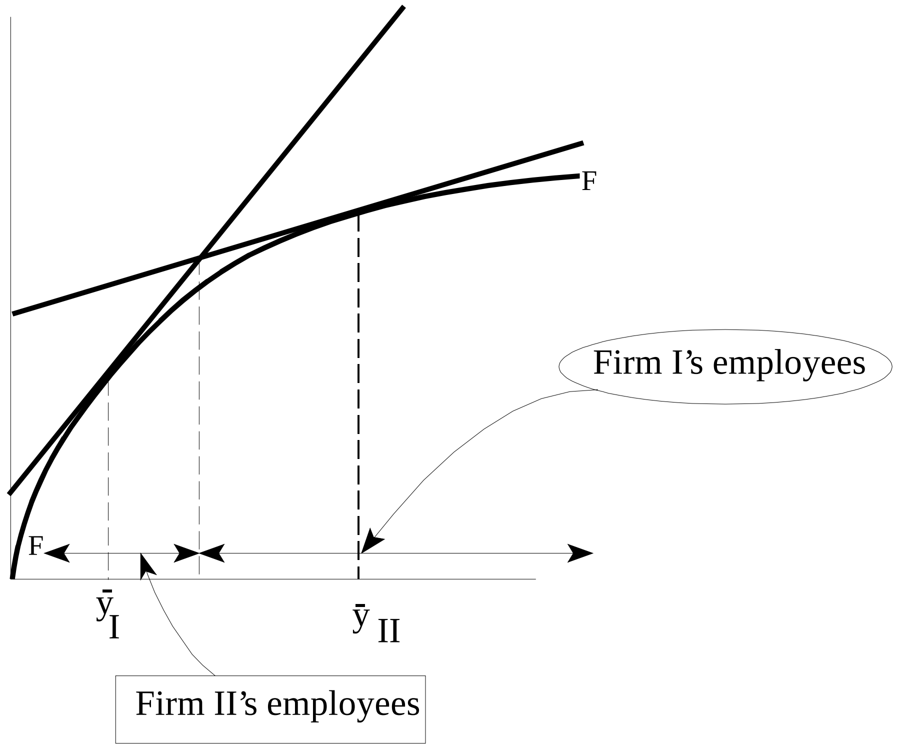

Figure 4a: The S-shaped case (a)

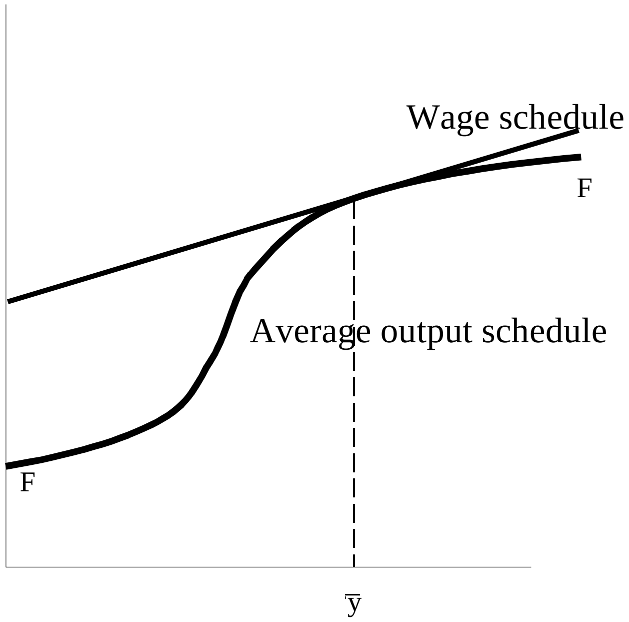

Figure 4b: the S-shaped case (b)