The Macroeconomics of Superstars

Anton Korinek
Johns Hopkins and NBER

Ding Xuan Ng
Johns Hopkins

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Abstract

Recent technological changes have transformed an increasing number of sectors of the economy into so-called superstars sectors, in which a small number of entrepreneurs or professionals distribute their output widely to the rest of the economy. Examples include the high-tech sector, sports, the music industry, management, finance, etc. As a result, these superstars reap enormous rewards, whereas the rest of the workforce lags behind. We describe superstars as arising from digital innovations, whicih replace a fraction of the tasks in production with information technology that requires a fixed cost but can be reproduced at zero marginal cost. This generates a form of increasing returns to scale. To the extent that the digital innovations are excludable, it also provides the innovator with market power. Our paper studies the implications of superstar technologies for factor shares, for inequality and for the efficiency properties of the superstar economy.

1 Introduction

Technological progress in the digital arena and in machine intelligence has greatly accelerated in recent years and has triggered large societal changes. One of the implications of this type of progress has been to transform an increasing number of sectors into so-called superstars sectors. This makes it of critical importance to understand the forces at work and examine lessons for how to design public policies to deal with the superstar phenomenon and the resulting increase in inequality.

This paper develops a macroeconomic model of the superstar phenomenon and studies its implications for factor rents, inequality and efficiency. We describe an economy in which there is a continuum of sectors served by traditional competitive firms. A traditional sector turns into a superstar sector when an entrepreneur comes up with what we call a *digital innovation* – an innovation that allows her to replace a fraction of the tasks in production using digitization and information technology. An important property of information is that is non-rival – this implies that, although the digital innovation requires a fixed cost, it can be reproduced widely at zero marginal cost, which generates a form of increasing returns to scale. (To cite a simple example, once an online travel agency has programmed its website, it can easily displace tens of thousands of traditional travel agents without much effort – since the website just needs basic computing resources, it scales almost costlessly.) If the innovation is excludable, it also provides the innovator with market power. The trade-off between cost savings from digital innovation and market power is one of the major themes of our paper.

We identify three channels through which the introduction of a digital innovation in one sector affects the economy: First, there is a *factor- (or labor-)replacing effect* since a fraction of production tasks in the sector is made redundant, and the demand for labor and capital declines in proportion. Second, the innovator uses her newly-gained market power to charge a markup and earn a monopoly rent, which we term the *superstar profit share*. If the innovator's cost reductions are relatively small, this mark-up is bounded by competition from traditional firms, and the innovator absorbs the entire cost savings in the form of a markup, i.e. the losses of traditional factor owners equal the gains of superstars. If the cost reductions are larger, then the innovator can charge her optimal monopoly price while still undercutting the firms using traditoinal technologies, and a third effect arises, which we term the *output scale effect*: given the lower prices, demand for the superstar's output rises, which increases both factor demand for capital and labor and superstar profits. the any additional wealth created by superstars creates some extra demand for all goods, including goods from traditional sectors. This effect increases the demand for traditional labor and partly offsets the labor-saving effect and the decline in wages described earlier.

In general equilibrium, digital innovations across a range of sectors always lead an increase in output. As long as the cost reductions are relatively small, however, the entire increase in output is absorbed by a rising superstar profit share, and the labor and capital share decrease. Conversely, once the cost savings surpass a critical threshold, output continues to rise but the labor, capital, and superstar profit share in the rising level of output remain constant.

We also use the model framework to study the described superstar phenomenon from a normative perspective and describe its efficiency properties. Compared to the first best, enterpreneurs in our model under-innovate since they inefficiently restrict supply to charge a monopoly premium. A natural policy measure is thus to provide as many digital innovations as possible as free public goods. In the limit, this would make the superstar phenomenon disappear, and all digital innovations would simply show up as productivity increases.

Relationship to the literature We innovate on the existing body of economic literature in two main respects. First, we contribute a macroeconomic perspective to a strand of literature that describes the "economics of superstars" (e.g. Rosen, 1981) from a microeconomic dimension, without analyzing the implications for the rest of the economy, including the implications for those left behind. We are the first to study the broader macroeconomic implication of the superstar phenomenon in an increasing number of sectors of the economy, we link it to the increase in income inequality that has occurred in recent decades, and we make predictions on the future path of inequality. The second related strand of literature describes recent increases in inequality as resulting from phenomena such as skill-biased technological change, which changes e.g. the share of income earned by the top-quartile vs. the bottom-quartile of the income distribution, but does not specifically consider the role of superstars (see e.g. Autor, 2013). However, most data sources on inequality show that it is really the top 0.01% (or even smaller percentiles) of the income distribution that amass the vast majority of gains – this relates much more closely to superstars than to highly-skilled workers.

Since Rosen (1981), economists have entertained the view that certain types of technological change can significantly enhance the productivity advantages of talented workers. In Rosen's view, new technology reduces the marginal costs of production for these 'superstar' individuals, which enables them to increase production and, by virtue of their greater ability (or quality of output), win larger market shares and extract greater rents. Rosen had in mind such technological changes as the television for comedians, and the radio for musicians. A common feature of these examples is that they allowed the production of a single 'unit' of services to be rendered to a larger pool of consumers. With the rise of the internet and rapidly improving communications technologies, the past 20 years have seen advancements in exactly the types of technologies that Rosen envisioned would lead to 'superstar' effects. While Rosen focused primarily on the positive effects of such technological changes on equilibrium prices and market shares, his model has obvious implications on the distribution of income and wealth in jobs affected by advances in superstar technology. More recent work has investigated these distributional effects. Gabaix and Landier (2008) and Garicano and Rossi-Hansberg (2006), among others, have used versions of this same mechanism to explain the rapid growth of income share in the far-right tails of CEO's and managers. Gabaix and Landier (2008) model the matching of the best CEOs to the largest firms, while Garicano-Rossi and Hanberg (06) model the rise in wages for the most productive managers as communication costs decline.

On a macroeconomic level, there is abundant evidence that these distributional changes are indeed in effect. Piketty and Saez (2001) documented that the income share for the top 0.1% of earners in the US has increased rapidly in the 1990's and 2000's, and that trend has continued since the publication of their paper. Investigating the occupational composition of the top 0.01% of earners over time using IRS data, Kaplan and Rauh (2010) find that the share of financial executives, lawyers and athletes has increased substantially. Bakija et al. (2012), using more complete IRS data, find additionally that even within the upper percentiles of these occupations, income inequality has increased substantially.

Beyond the income distribution of earners, technology that enables superstar earners has also been associated with a small number of firms acquiring high market concentration (see Brynjolfsson et al. (2010)). Evidence collected by Mueller et al. (2015) shows that the average size of the largest firms has increased very significantly in fourteen of the fifteen countries they study between the mid-1980s or mid 1990s and 2010. The average size of the top 50 (100) firms in the US grew by 55.8% (53.0%) between 1986 and 2010.

Finally, technological change has also been investigated as a cause of the declining labor share. Karabarbounis and Neiman (2013) and Alvarez-Cuadrado et al. (2014) document that the labor share of income has declined steadily from the 1970's to the 2000's. Autor et al. (2017) show that the labor share of income has also been declining at the firm and establishment level, and show that industries that have seen the largest rise in market concentration have also tended to see the starkest declines in labor share.

Thus far, work on superstars has largely concentrated on modelling the effects of superstar technology on the distribution of earnings within occupations (of managers and CEOs, for example), or on the market structure in an industry (e.g. Noe and Parker (2005) investigate how the web-based sector produces a "winner-take-all" market). By contrast, we examine the macroeconomic effects of superstar technologies and ask how superstar technologies lead to rising income inequality, rising market concentration and a declining labor share. Secondly, we investigate the welfare effects of the introduction of superstar technologies. In particular, do the returns from implementing superstar technology occur as a result of rising monopoly rents accruing to owners of the superstar technology, or rather as a result of compensation for increased productivity from new technology? This question hits at the heart of a topic of contention in the literature on superstar CEO compensation. Edmans and Gabaix (2008), among others, construt assignment models that suggest that rising superstar compensation is efficient, in line with rising individual productivity. On the other hand, Bebchuk and Fried (2004), among others, argue that increased ability to extract rents by superstar managers accounts for their rising earnings.

We provide a model that introduces the superstar entrepreneur as a factor of production who implements superstar technology in production, and owns the new technology. Our model articulates how the introduction of the superstar entrepreneur can lead to inequality along three dimensions - income inequality, declining labor share of income, and increasing market share of superstar firms. The model does this through through two main mechanisms. First, adoption of superstar technologies allows entrepreneurs to extract greater rents from monopoly power and increasing scale. This provides incentives for these firms to adopt superstar technologies, and provides high returns to the entrepreneurs behind those firms. Secondly, superstar firms lead to increasing market concentration as traditional firms need to scale down production. At first, demand for labor declines in aggregate, while labor supply is unchanging. Wages stagnate and employment declines, leading to a decline of the labor share. Later, wages increase again as

Existing explanations for rising income inequality and the declining labor share include Autor and Dorn (2013) and Karabarbounis and Neiman (2013) who posit that the decline in the relative price of computer capital to labor is an important explanation. Elsby et al. (2013) argue for the importance of trade and international outsourcing, and they present evidence indicating that the labor share declines the most in U.S. industries that were strongly affected by increasing imports (e.g., from China). Piketty (2014) also stresses the role of social norms and labor market institutions, such as unions and the real value of the minimum wage. Nevertheless, we show that the adoption of superstar technologies, by increasing firm size and promoting higher market concentration, is a distinct and very plausible explanation for these macroeconomic phenomena.

1.1 Empirical Motivation

The macroeconomic relevance of the superstar phenomenon is underlined by a number of trends in the data, which we examine in the remainder of this section. We first discuss evidence on the rise of superstars, both among individuals – captured by an increase in the right tail of the income distribution – and among firms – captured by increasing market concentration. Then we discuss recent evidence on the decline in traditional factor shares and the rise in monopoly rents, which we interpret as superstar profits.

Fat Right Tails in Individual Income Distribution Rosen's original paper provided a model for how superstar technology can produce incomes (or more accurately, a profit function) that are convex in talent, providing the justification for right-skewed income distributions. In other words, if the superstar effect is indeed significant, we should see the emergence of fat tails, or long tails, on the right of the income distribution. Indeed, the data bears this out.

Overall Income Distribution Since the publication of their 2003 paper with estimates of the US income distribution from 1913-1998, Piketty and Saez have provided updates to their data. The latest is the update to 2015, and Fig 1 shows the change in the income shares (including capital gains) of the top 1%, top 5%-1%, and top 10%-5% of earners from 1913-2015.

The figure shows that while the income share of the top 10%-5% and 5%-1% have been increasing steadily since the end of WWII, the income share of the top 1% stagnated and even declined from 1945-1980, but has risen much more steeply from the 1980's onwards. While the rise has been steep, it has also been volatile, with large declines during periods of recession. These observations suggest that the superstar phenomenon is reflected in the

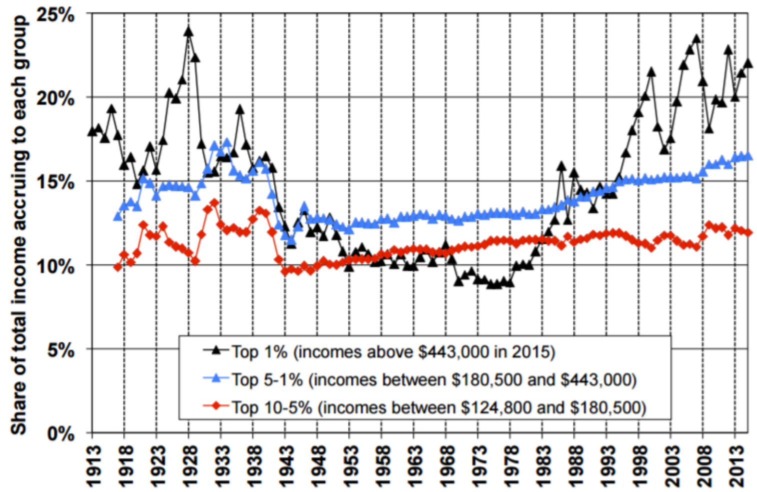

Figure 1: Top income shares *(Source: Piketty and Saez, 2015)*

data as a significant increase in top incomes as well as a hollowing-out of the middle class, giving rise to growing inequality.

Top percentile Using confidential IRS data with 100% sampling from the top 0.1% of earners from 1979 to 2005, Bakija, Cole and Heim (2012) decompose the top 0.1% by occupation. They show that the occupations that have seen the largest increases in their representation in the top 0.1% of earners are Real Estate, Financial Professions, and Arts, Media and Sports occupations. Furthermore, there is increasing divergence even between the top 0.1% and top 0.5%. For example, for non-finance executives, the earnings ratio of the top 0.1% compared to the remainder of the 0.5% increased by 7 times between 1979 and 2005. This suggests that "super-"superstars are increasingly diverging from the rest of the pack of superstars.

Market Concentration For firms, Figure 2 plots the average growth rate of the concentration of sales of all industries. Industries became less concentrated through the early 1990s. Concentration drops at the fastest rate in year 1995. After 1997, average industry concentration has increased unabatedly.

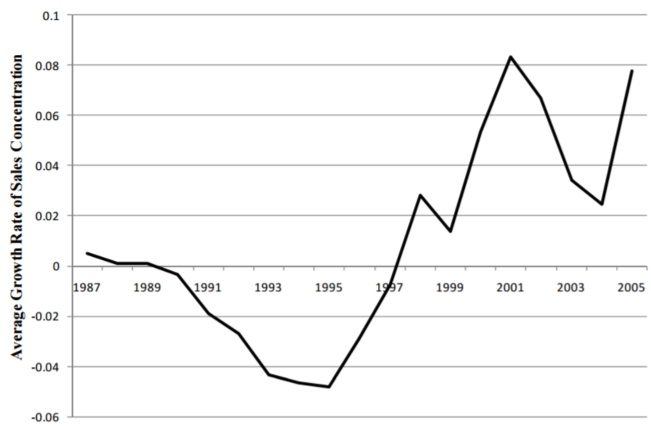

Figure 2: Growth of sales concentration *(Source: Brynjolfsson et al., 2010)*

Market Concentration by Sector Figure 3 from Autor et al. (2017) plots an indicator for industry concentration in six major sectors of the U.S. economy. They calculate industry concentration for each four-digit industry code and present averages across industries for each of the six sectors. For each industry, the solid blue line and dashed green line (both marked with circles) show the average fraction of sales accounted for by the largest four and twenty firms in that industry, respectively. The solid red line and dashed orange line (both marked with triangles) show the average fraction of industry employment in the four and twenty largest firms, respectively. All of them have experienced marked upward trends. Employment shares being smaller than sales shares suggests that the largest firms employ disproportionately fewer workers. Autor et. al (2017) also argue that the rise in market concentration by 'superstar firms' is an important cause of the fall in labor share. If superstar technologies are indeed leading to a rise in market concentration, then we may expect to see a coincident fall in labor share within sectors.

Factor Shares and Monopoly Rents Barkai (2017) estimates that the labor share and the traditional capital share in total US GDP have declined by about 7 percentage points each between 1984 and 2014, allowing what he terms the profit share to increase by 14 percentage points. Our interpretation of the phenomenon is that it largely constitutes increased superstar profits.

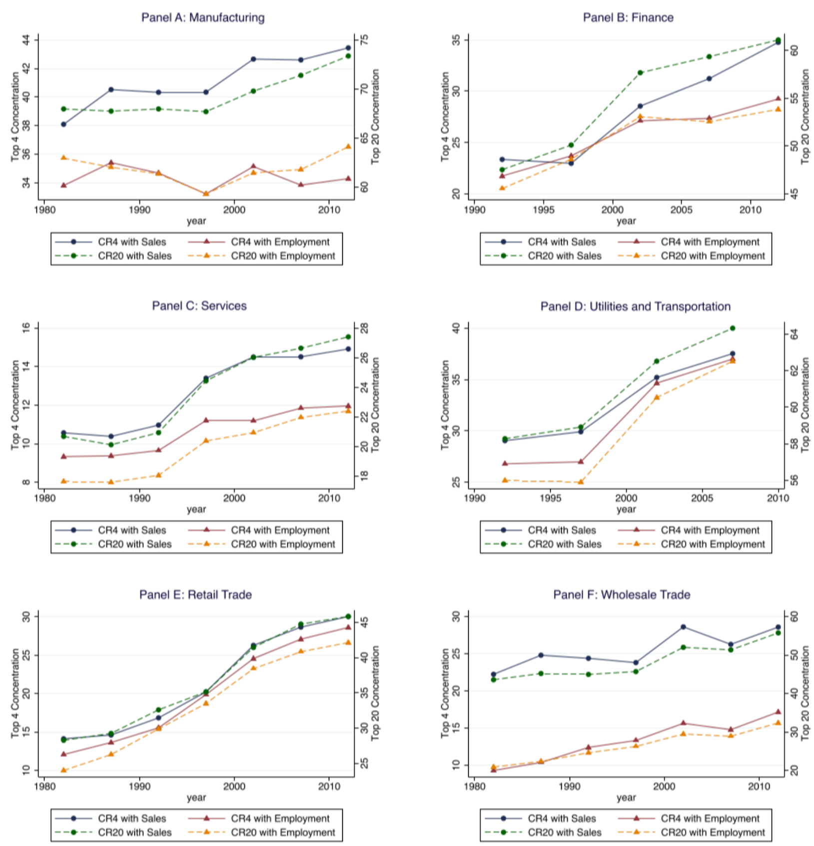

Figure 3: Increasing market concentration *(Source: Autor et al., 2017)*

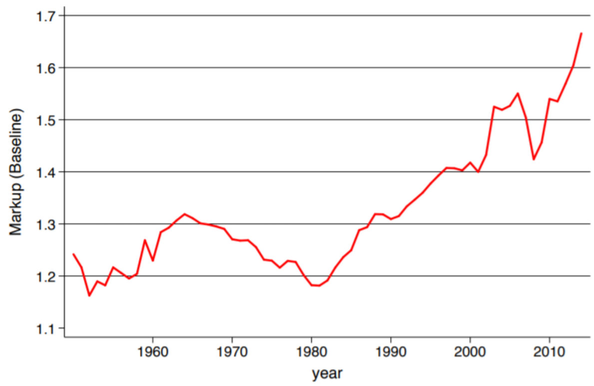

Figure 4: Increasing markups *(Source: De Loecker and Eeckhout, 2017)*

De Loecker and Eekhout (2017) use firm level panel data to show that the average markup of firms over marginal cost has increased from 18% in 1980 to 67% in 2014, as shown in Figure 4. They observe that this increase is not uniform but concentrated around a relatively small number of firms, consistent with the superstar phenomenon. They also analyze the macroeconomic implications of increased markups. Our paper builds on their findings but develops a theory behind the rise in markups, allowing us to connect technological change in the form of digital innovation to the increases in market concentration and analyzing the welfare implications of the resulting superstar phenomenon.

2 Baseline Model

Our baseline model is set in a static economy in which there is a unit mass of consumers who are homogenous, except that a variable fraction θ may also be active as superstar entrepreneurs. There are two traditional factors of production, capital and labor, as well as a unit mass of differentiated intermediate goods and a final good which serves as numeraire. Each consumer inelastically supplies an endowment of labor $L = 1$ and capital $K > 0$ which fully depreciates in production, earning competitive wage W and rental rate R. Furthermore, consumers also earn profits Π^T from the activities of traditional firms, which we will describe below. They consume their total income in terms of final goods

$$C = W + RK + \Pi^T$$

and obtain utility from consumption according to the neoclassical utility function $u(C)$. Consumers who are also active as superstar entrepreneurs earn and consume in addition the superstar profits Π^S described below.

Final Goods are obtained by combining a unit mass of differentiated intermediate goods indexed $i \in [0,1]$ in a Dixit-Stiglitz production function

$$Y = \left(\int_0^1 Y_i^{1-\frac{1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}, \tag{1}$$

where we assume that the elasticity of substitution $\epsilon > 1$. Given that the price of final goods serves as numeraire, the relative prices of intermediate goods satisfy the usual price index equation $P = \left(\int P_i^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}} \equiv 1$. The demand function for each good i is

$$Y_i = (P_i)^{-\epsilon} Y$$

which can easily be inverted into an inverse demand function $P_i(Y_i; Y) = (Y_i/Y)^{-1/\epsilon}$.

Traditional Firms There is a large number of competitive firms in the each sector i who have access to what we call a *traditional* production technology. Firms using this technology produce output by hiring labor and capital in a competitive factor market and combining them according to the Cobb-Douglas production technology

$$Y_i = F_i(K_i, L_i) = A_i K_i^\alpha L_i^{1-\alpha}$$

The optimal factor demands of traditional firms are $K_i^T(Y_i; R, W) = \left(\frac{\alpha}{1-\alpha} \cdot \frac{W}{R} \right)^{1-\alpha} / A_i$ and $L_i^T(Y_i; \cdot) = \left(\frac{1-\alpha}{\alpha} \cdot \frac{R}{W} \right)^\alpha / A_i$, where the superscript T refers to *traditional* firms. The resulting total cost function $TC^T(Y_i)$ for firms employing traditional technology, and the corresponding unit cost UC_i^T, which both depend on factor prices R and W, are

$$TC_i^T(Y_i) = \left(\frac{R}{\alpha} \right)^\alpha \left(\frac{W}{1-\alpha} \right)^{1-\alpha} \frac{Y_i}{A_i}$$

$$UC_i^T = \left(\frac{R}{\alpha} \right)^\alpha \left(\frac{W}{1-\alpha} \right)^{1-\alpha} / A_i$$

As long as only firms employing the traditional technology are active in sector i, competitive behavior implies that the price of the intermediate good i is pinned down by the unit cost function of traditional firms,

$$P_i = UC_i^T \tag{2}$$

giving rise to a quantity demanded and produced of

$$Y_i^T = \left(UC_i^T\right)^{-\epsilon} Y$$

Superstar Firms When a firm invents a new digital innovation that allows it to automate a fraction of the tasks required to produce output and the firm can exclude others from using this innovation, it turns into a superstar firm. In our baseline model, we assume that there is at most a single superstar firm in each sector. (We will generalize this below in section 4.1). More specifically, we assume that a superstar firm has the option to spend a fixed user cost ξ_i to automate a fraction γ_i of the tasks involved in production, enabling it to produce output at marginal cost $MC_i^S = (1-\gamma_i)\,UC_i^T$, where the superscript S refers to the *superstar* firm. For reasons of analytic simplicity, we denote the user cost ξ_i w.l.o.g. in terms of units of the traditional technology UC_i^T, leading to a total cost function

$$TC_i^S\left(Y_i\right) = \xi_i \cdot UC_i^T + UC_i^S \cdot Y_i = \left[\xi_i + (1-\gamma_i)\,Y_i\right] \cdot UC_i^T$$

One of the most natural interpretations of this setup is that the firm replaces a fraction γ_i of the tasks involved in production using digitization and information technology that can be scaled at close-to-zero cost. The fixed cost ξ_i in our example can be interpreted as the sum of the annualized value of any initial investment in establishing the superstar technology plus any fixed platform cost that accrues per time period to run the technology.

This captures that a large number of sectors can automate a fraction of the tasks involved in producing or providing their product by creating digital innovations that reduce the marginal cost of providing their product to one more customer. Many practical examples arise in the service sector, in which firms provide their products digitally and/or interact with their customers over the Internet, cutting down significantly on costs. This includes the music, entertainment and sports sectors, which stream their products (or, in earlier days, produced digital or analog copies) instead of performing live in front of their customers, as was necessary in the 18th century, producing a number of well-known superstars; the office work sector, in which a large fraction of secreterial work has been replaced by personal computers and office suites that are provided by superstar firms like Microsoft; the travel industry, in which the majority of travel agents have long been replaced by websites that perform the same function at zero marginal cost, producing superstar online travel companies that intermediate the vast majority of travel services; the financial sector, in which customers increasingly interact with their institutions via expensive digital platforms that create a strong impetus to merge into superstar firms. In the retail sector, online shopping superstars such as Amazon have made significant inroads in replacing regular brick-and-mortar stores that provide retail services. According to many experts, the transportation sector is at the cusp of a revolution after which its services will be performed by driverless cars and trucks, programmed by a handful of superstar providers. Even in manufacturing, an increasing number of firms employ digital innovations to automate significant parts of the production process. For example, Nike, one of the superstars in athletic wear, recently announced that it is working on a proprietary robot technology to automate the production of footwear, cutting its unit labor costs in half (FT, 2017).

A superstar firm that deploys its automation technology chooses a level of output to maximize profits,

$$\max_{P_i,Y_i} \pi^S(Y_i) = P_i Y_i - TC_i^S(Y_i) \qquad \text{s.t.} \qquad P_i = P(Y_i;Y) \le UC_i^T \tag{3}$$

The constraint captures that the superstar firm internalizes its market power, i.e. that the market price of its goods $P_i(Y_i;\cdot)$ depends on the quantity produced, and that the superstar firm cannot set a higher price than the price at which traditional firms would compete with the superstar firm. If this constraint is binding, then the superstar firm will simply set $P_i = UC_i^T$. For simplicity, we assume that all output is produced by the superstar firm in that case (the superstar firm would push any competing traditional firms out of the market by lowering the price by an infinitesimal amount). Otherwise, if the constraint is slack, the superstar firm's output is determined by the optimality monopoly pricing condition

$$\underbrace{P_Y(Y_i;\cdot)Y_i + P_i(Y_i;\cdot)}_{\text{Marg Rev.}} = \underbrace{(1-\gamma_i)\,UC_i^T}_{\text{Marg Cost}}$$

Given the Dixit-Stiglitz production function for final goods, the optimality condition can be simplified and combined with the constraint imposed by competitive traditional firms into the markup pricing rule

$$P_i^S = \mu_i \cdot (1-\gamma_i) \cdot UC_i^T \qquad \text{where} \qquad \mu_i = \min\left\{\frac{1}{1-\gamma_i}, \frac{\epsilon}{\epsilon-1}\right\} \tag{4}$$

Intuitively, when the cost savings from automation are small ($\gamma_i < 1/\epsilon$), the superstar firm is constrained by the potential competition from traditional firms and charges the competitive price of firms using the traditional technology, satisfying all the demand that prevails at that price. In that region, superstar firms absorb all their cost savings as rent. When automation has proceeded sufficiently far in comparison to the demand elasticity that the superstar firm can charge its optimal monopoly markup and still undercut traditional firms ($\gamma_i \geq 1/\epsilon$), then the monopoly price prevails, and competition from traditional firms is irrelevant for the superstar firm.

The quantity demanded from the superstar firm is accordingly

$$\begin{aligned} Y_i^S &= \left(P_i^S\right)^{-\epsilon} Y = \left[\mu_i \cdot (1-\gamma_i) \cdot UC_i^T\right]^{-\epsilon} Y \\ &= \left[\mu_i \cdot (1-\gamma_i)\right]^{-\epsilon} Y_i^T = \max\left\{1, \left(\frac{\epsilon\,(1-\gamma_i)}{\epsilon-1}\right)^{-\epsilon}\right\} \cdot Y_i^T \end{aligned}$$

The superstar firm always produces at least as much as the traditional sector.

It is only profitable to deploy the superstar technology if the markups plus cost savings from automation that the firm can obtain allow it to recoup the fixed cost ξ_i,

$$(\mu_i - 1)\,(1-\gamma_i)\,Y_i^S \geq \xi_i \tag{5}$$

2.1 Digital Automation and the Superstar Effect

This section analyzes how progress in digital automation, captured by increases in the cost-saving parameter γ_i from zero to close to one, affect the equilibrium of a given sector i of the economy. In particular, we focus on the implications for factor demand and monopoly rents in sector i.

Proposition 1 (Digital automation and the superstar effect)**.** *(i) As long as the cost savings from digital automation are small relative to the inverse demand elasticity, $\gamma_i < 1/\epsilon$, a superstar firm entering the market charges the traditional price P_i^T because of competition from traditional firms and produces the traditional firm quantity Y_i^T. In this region, increases in automation linearly reduce demand for capital and labor and* *linearly increase superstar profits, since all cost savings are absorbed in the form of monopoly profits.*

(ii) Once automation exceeds the threshold $\gamma_i > 1/\epsilon$*, a superstar firm entering the market charges a lower price* $P_i^S < P_i^T$ *than the price of traditional firms, given by the optimal monopoly markup* $\frac{\epsilon}{\epsilon-1}$ *over its costs, and output rises above the output of traditional firms,* $Y_i^S > Y_i^T$*. Increases in automation reduce the price charged by the superstar firm linearly, but raise demand for capital and labor as well as output and superstar profits in a convex fashion. If* $\gamma_i \to 1$*, the sector reaches a singularity at which output goes to infinity.*

(iii) The superstar firm finds it optimal to enter the market and displaces all firms using the traditional technology once automation has reached a threshold $\gamma_i \geq \hat{\gamma}_i$*.*

Proof. For point (i), observe that the threshold $\hat{\gamma}_i$ implies that superstar firms break even. At the threshold, the superstar profit is just sufficient to cover the fixed cost of operating the superstar technology.

For point (ii), observe that our earlier discussion implies the price charged $P_i^S = UC_i^T$ and output level $Y_i^S = Y_i^T$. Given constant output, factor demand is $L_i^S = (1-\gamma_i) L_i^T$ and $K_i^S = (1-\gamma_i) K_i^T$, which is linearly decreasing in γ_i, and superstar profits $\pi_i^T = \gamma_i Y_i^T$, which are linearly increasing.

For point (iii), observe that superstar output is given by $Y_i^S = \left[(1-\gamma_i) \frac{\epsilon}{\epsilon-1} UC_i^T\right]^{-\epsilon} Y \simeq (1-\gamma_i)^{-\epsilon}$, which satisfies

$$\frac{dY_i^S}{d\gamma_i} \simeq \epsilon (1-\gamma_i)^{-\epsilon-1} > 0$$
$$\frac{d^2 Y_i^S}{d(\gamma_i)^2} \simeq \epsilon(\epsilon+1)(1-\gamma_i)^{-\epsilon-1} > 0$$

Given the Cobb-Douglas production function for the variable component of the superstar technology, factor demand is

$$L_i^S\left(Y_i^S; Y\right) = \left(\frac{1-\alpha}{\alpha} \cdot \frac{R}{W}\right)^{\alpha} \frac{(1-\gamma_i) Y_i^S}{A_i} \simeq (1-\gamma_i) Y_i^S \simeq (1-\gamma_i)^{-\epsilon+1}$$

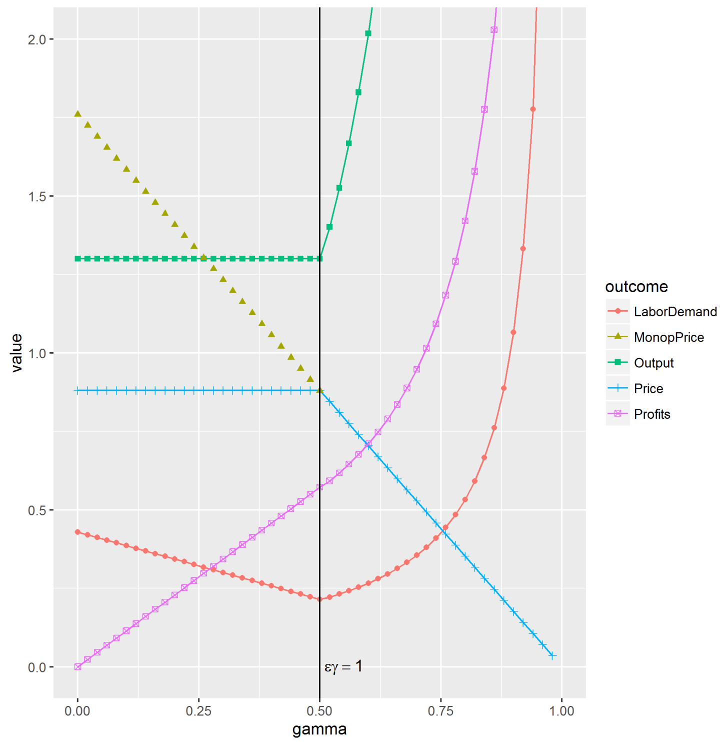

Figure 5: Automation and the superstar effect

which satisfies

$$\frac{dL_i^S}{d\gamma_i} \simeq (\epsilon-1)(1-\gamma_i)^{-\epsilon} > 0$$
$$\frac{d^2 L_i^S}{d(\gamma_i)^2} \simeq (\epsilon-1)\,\epsilon\,(1-\gamma_i)^{-\epsilon-1} > 0$$

and similar for capital demand $K_i^S\left(Y_i^S,\cdot\right)$.

The revenue of the superstar firm is given by $R_i^S = P_i^S \cdot Y_i^S = \left[(1-\gamma_i)\frac{\epsilon}{\epsilon-1} UC_i^T\right]^{-\epsilon+1} Y \simeq (1-\gamma_i)^{-\epsilon+1}$ with derivatives w.r.t. γ_i of identical signs as for factor demands. Superstar profits are given by a constant share of revenue, which satisfies the same inequalities. □

The intuition for points (ii) and (iii) of the Proposition 1 is also illustrated in Figure 5, in which we assume for simplicity that $\xi_i = 0$. As we start from low levels of automation, the superstar's cost savings compared to traditional firms are at first relatively small, and its optimal monopolistic pricing strategy (green diamonds) is constrained by the threat of competition from traditional firms, inducing superstar firms to charge the price that would be charged by traditional firms (blue crosses). In this region, increasing digital automation induces the superstar firm to absorb any cost savings via increased markups and profit margins (pink boxes), without increasing output (green squares). And given that output remains constant, rising levels of digital automation imply that the superstar firm reduces its demand for the traditional factors capital and labor in that region (red circles). As a result, only the *labor- (or factor-)saving effect* of technological progress is present.

However, once the cost savings of the superstar firm are larger than the desired monopoly markup, indicated by the vertical line, the superstar firm passes any additional cost savings on to consumers via lower prices in order to boost demand for its output, benefitting consumers. In this region, improvements in the automation technology induce the superstar firm to lower prices (blue crosses) but increase production (green squares). Given that we assumed the demand for the firm's output is relatively elastic ($\epsilon > 1$), lower prices induce a sufficient increase in demand and production so that total revenue increases, of which the superstar firm absorbs a fixed share in monopoly rents (pink boxes). By the same token, the increase in quantities also outweighs the lower factor requirements per unit produced so that total factor demand by the superstar firm increases (red circles). As a result, the factor-saving effect of technological progress is outweighed by what we may call an *output scale effect* of technological progress.

Superstars and factor shares

We next focus on factor shares in the econmoy and on how technological progress among superstars, captured by a marginal increase in the cost savings parameter γ_i, affects these factor shares. The following results hold for an individual sector in the economy, taking aggregate factor prices as given:

Corollary 1 (Increasing automation and factor shares)**.** *(i) An individual sector i in which a superstar has entered exhibits a superstar profit share of*

$$\sigma = \min\{\gamma_i, {}^1\!/\!_\epsilon\} \tag{6}$$

as well as a capital share of $\alpha(1-\sigma)$ *and a labor share of* $(1-\alpha)(1-\sigma)$*.*

(ii) As long as $\gamma_i < 1/\epsilon$, a marginal increase in γ_i leaves output unchanged but reduces the labor and capital shares while commensurately increasing the superstar profit share. When $\gamma_i \geq 1/\epsilon$, further marginal increases in γ_i raise output but leave the labor, capital and superstar profit share constant.

Proof. The result follows from Proposition 1. □

The intuition for the corollary is that as long as automation is in its early stages and $\gamma_i < 1/\epsilon$, superstars simply absorb all their cost savings γ_i since their price charged remains at the level of traditional firms. Once the inequality is reversed, superstars can increase their profits by charging the optimal monopoly (gross) markup $1/\epsilon$ and increasing the quantity supplied. This implies a ceiling for the profit share of superstar monopolists that is determined by consumer preferences, i.e. by consumers' elasticity of substitution among intermediate goods.

The superstar factor So far we have analyzed the economic changes arising from digitial innovation and the superstar phenomenon by describing the effects of replacing a fraction γ_i of the tasks involved in producing sector i output with a perfectly scalable digital technology. In the following, we illustrate that the introduction of a superstar technology can equivalently be described as introducing a new "superstar factor" into the production function of the economy.

Corollary 2 (The Superstar Factor)**.** *The allocations chosen by a superstar sector i are equivalent to what would be chosen by a competitive firm that employs $S_i = 1$ units of a superstar factor in the production technology*

$$\tilde{Y}_i = \tilde{F}_i\left(K, L, S\right) = \begin{cases} \frac{(1-\gamma_i)^{\gamma_i}}{1-\gamma_i}\left(K_i^{\alpha} L_i^{(1-\alpha)}\right)^{1-\gamma_i} S^{\gamma_i} & \textit{if } \epsilon\gamma_i < 1 \\ \left(\frac{1}{1-\gamma_i} K_i^{\alpha} L_i^{(1-\alpha)}\right)^{\frac{\epsilon-1}{\epsilon}} S^{\frac{1}{\epsilon}} & \textit{if } \epsilon\gamma_i \geq 1 \end{cases}$$

Proof. □

Intuitively, the formulation in Corollary **??** implies that a competitive firm that has access to the indicated production function will choose the same levels of capital, labor and produce the same level of output as the superstar firm described in Proposition 1. Furthermore, the Cobb-Douglas structure implies that the capital, labor and superstar profit shares are given by $\alpha\left(1-\sigma\right)$, $\left(1-\alpha\right)\left(1-\sigma\right)$ and σ, respectively.

2.2 General equilibrium results

Let us now consider the general equilibrium of our static benchmark economy. In the following, we assume w.l.o.g. a symmetric equilibrium in which all sectors share the same baseline technology $A_i = A$ and automation parameter $\gamma_i = \gamma$. In such a symmetric equilibrium, (1) implies that aggregate output is given by

$$Y = \frac{A}{1-\gamma} K^{\alpha} L^{1-\alpha} \tag{7}$$

At the same time, equation (6) indicating the share of output accruing to superstars continues to apply, which implies that wage and capital income are given by

$$w = (1-\alpha)(1-\sigma) Y \tag{8}$$

$$RK = \alpha \ (1-\sigma) Y \tag{9}$$

Proposition 2 (Output in general equilibrium)**.** *(i) A symmetric increase in γ across all sectors leads to a convex increase in aggregate output.*

(ii) As long as $\gamma < 1/\epsilon$, an increase in γ linearly reduces labor and capital shares while commensurately increasing the superstar profit share. Wages and the return on capital remain constant and superstars absorb all the increase in output.

(iii) When $\gamma \geq 1/\epsilon$, further increases in γ raise output but leave the labor, capital and superstar profit share constant. Wages and the rental rate of capital increase in line with output.

(iv) As $\gamma \to 1$, the economy reaches a singularity at which output and all factor income go to infinity.

Proof. Result (i) is obtained by observing that equation (7) is a convex function of γ. For (ii), we observe that the superstar factor share satisfies $\sigma = \gamma$ in this region. We substitute this together with (7) into equations (8) and (9) to obtain the result. For (iii), we use instead the superstar factor share $\sigma = 1/\epsilon$, which is relevant in the described region. Point (iv) is a straightforward limit result. □

Our general equilibrium results differ in important aspects from the partial equilibrium results of Proposition 1, as is also illustrated in Figure 6 for the case of $\xi_i = 0 \forall i$:

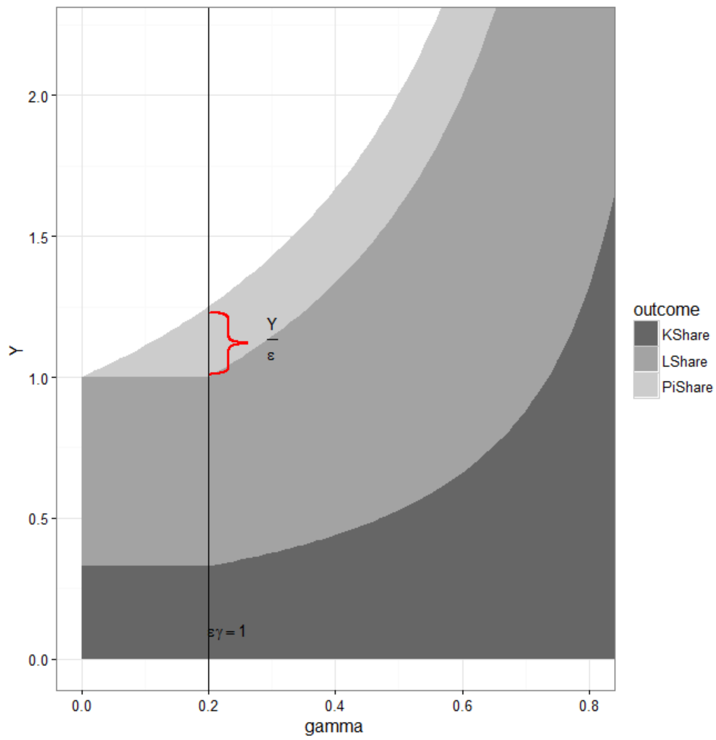

Figure 6: Factor shares as a function of automation

As long as $\gamma_i < 1/\epsilon$, individual firms in partial equilibrium do not increase output, but reduce their factor demand. However, in general equilibrium, this decline in factor demand reduces wages and the return on capital, lowering all firms' unit costs – no matter if they use the traditional or superstar technology – sufficiently so that they increase output and absorb the available factor supply. As a result, output in general equilibrium goes up, although all the gains accrue to the superstars (see the blue top area).

Once digital automation exceeds the threshold $\gamma_i \geq 1/\epsilon$, monopolist superstars set a constant price markup over their costs in all sectors. Further increases in digital automation γ_i lead to price declines of the intermediate goods across all sectors, triggering an increase in aggregate demand and output – due to the scale effect of Proposition 1. The mechanism through which the rise in output is shared among all three factor owners is that greater demand for labor and capital pushes up wages and the interest rate. As a result, the share of superstar profits and the factor shares of labor and capital remain constant, as shown in the figure.

One important point to remember is that the described results compare the allocations of different static one-period economies, in which the supply of the factors capital and labor is taken as exogenous. Our results on wages and the rental rate of capital in points (ii) and (iii) of the proposition suggest that incentives to supply labor and capital are unaltered in the early stages of automation but are increased once the threshold $\bar{\gamma} = 1/\epsilon$ is surpassed. This implies that when factor supplies are endogenous, labor supply and capital accumulation will lag behind output growth in the early stages of digital automation, but additional capital accumulation and growth in capital and labor supply will occur once the threshold $\gamma_i \geq 1/\epsilon$ is crossed, as we will explore in further detail when we analyze macroeconomic dynamics in Section 5.

3 Welfare Analysis

The main inefficiency from the emergence of superstars is monopoly power that arises because superstars can exclude others from employing the innovation that they have developed. In our baseline model, the resulting monopoly rents at first compensate superstars for the cost ξ_i of developing the innovation and then generate windfall gains for the superstars.

This section evaluates the welfare properties of the described superstar economy. We start with a first-best perspective to analyze how a planner would employ superstar technologies under idealized circumstances. Then we consider what policy measures can be employed in a second-best world to mitigate the inefficiencies arising from the superstar phenomenon.

3.1 First best

In the first best, a social planner would choose the optimal mix of traditional and superstar technologies (captured by the indicator function $1_i^S = 1$ when the superstar technology in sector i is active), in order to maximize total output net of the total user costs of the superstar technology,

$$\max_{\{K_i, L_i, Y_i\}} \left(\int_0^1 Y_i^{1-\frac{1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}} \qquad \text{s.t.} \qquad Y_i = \max_{1_i^S} \left\{ \frac{A_i K_i^\alpha L_i^{1-\alpha} - 1_i^S \xi_i}{1 - 1_i^S \gamma_i} \right\} \forall i,$$

$$\int_0^1 K_i = K$$

$$\int_0^1 L_i = L$$

Proposition 3 (First Best and Monopoly Distortions from Digital Innovation)**.** *The decentralized equilibrium exhibits (i) insufficient digital innovation and (ii) inefficiently low quantities in superstar sectors compared to traditional sectors.*

Proof. See appendix.

□

The intuition behind our result is that private superstar firms charge a markup upon developing digital innovations, which – unsurprisingly – leads to inefficiently low quantities. This also implies that they do not generate the full social surplus that could be obtained from the superstar technology. As a result, the threshold $\hat{\gamma}_i$ at which they decide to innovate is insufficiently low. A first-best planner would employ the superstar technology to produce larger output and generate more social surplus, and therefore has greater incentive to innovate.

The inefficiencies described in the proposition refer to superstar sectors in comparison to traditional sectors. In our static setup, the monopoly power of superstar firms does not distort the aggregate level of capital but only its allocation across different industries. In our dynamic setup in Section 5, monopolistic superstar firms also distort the level of the capital stock downwards because they reduce the returns earned by traditional capital.

Corollary 3 (Correcting Monopoly Distortions)**.** *The inefficiency described in Proposition 3 can be corrected in the following ways:*

(i) by providing a subsidy $s_i = \sigma P_i$ *on the output of superstar firms to offset their monopoly markups;*

(ii) by using public funds to finance the fixed cost ξ_i *of socially desirable digital innovations and making them freely available to competitive traditional firms;*

(iii) by employing non-linear pricing schemes whereby superstars charge a fixed cost and satisfy the demand for their product at marginal cost.

Although the described policy options make production more efficient and implement the first best, they do not necessarily lead to Pareto improvements because they change the distribution of surplus. Option (i), to subsidize superstar firm output, increases demand for the output of superstar firms to the socially efficient level, but implies that superstar firms earn even larger monopoly profits, unless some of their profits can be taxed away in lump sum fashion. On the other hand, option (ii) implies that superstar profits disappear since anybody can use the efficient new technologies. However, if transfers are feasible, both policies (i) and (ii) can generate Pareto improvements. Option (iii) naturally delivers a Pareto improvement if the fixed cost is set to an appropriate level.

Naturally, all three proposed policies also come with important caveats in practice:

Option (i), subsidizing monopolistic firms requires large amounts of fiscal revenue, and raising this revenue may introduce large distortions of its own. Furthermore, it may be politically difficult to provide subsidies to firms that are already earning large monopoly rents.

Option (ii), public financing of digital innovation, also requires large amounts of fiscal revenue. Furthermore, it requires that innovation can be performed without additional agency costs, i.e. that researchers do not need to earn additional superstar rents to be incentivized to perform. Moreover, it requires that the information underlying the innovation is fully non-rival and can indeed be freely distributed without generating bottlenecks in its use (for example, because only a small number of experts can use it).

Option (iii), charging a fixed cost and satisfying demand at marginal cost, supposes detailed information about the structure of demand, including the ability to appropriately discriminate between consumers who derive different surplus and should therefore optimally be charged different fixed costs.

3.2 Second-best interventions

[to be written up]

4 Extensions

4.1 Market share dynamics

This subsection extends our baseline model to incorporate multiple superstar firms in a given sector vying for sectoral dominance. In our baseline model, we made the extreme assumption that there was at most a single superstar firm per sector so as to focus on clear and simple results. We now relax this assumption to examine the robustness of our anlaysis. We consider a sector i with a superstar firm $j = 1$ that has variable cost savings γ_{i1} and assume that a second superstar firm $j = 2$ can enter the sector by paying a fixed cost ξ_i and produce sector i goods with variable cost savings γ_{i2}.

The entrant and the incumbent engage in Cournot competition. This is thus a model of Cournot duopoly where firms have heterogeneous cost functions. The total output in sector i is the sum of the output of the two firms, $Y_i^D = Y_{i1} + Y_{i2}$, where we use the superscript D to indicate that it refers to the duopoly case. Each firm ij takes the output of the other firm as given and solves

$$\max_{P_{ij},Y_{ij}} P_{ij}Y_{ij} - (1-\gamma_{ij})\, UC_i^T Y_{ij} - \xi_{ij} \qquad \text{s.t.} \qquad P_{ij} = P\left(Y_{i1} + Y_{i2}; Y\right) \le UC_i^T$$

The optimality condition for firm j equates marginal revenue and marginal cost, $P_Y Y_{ij} + P_i = (1-\gamma_{ij})\, UC_i^T$, as in our baseline model.

Pricing Constrained by Traditional Technology When competition from traditional firms constrains the pricing of superstar firms, then they charge the price given by the unit cost of traditional firms $P_{ij} = UC_i^T$ and jointly produce the output that would be produced by traditional firms, $Y_i^D =$

$Y_{i1}+Y_{i2}=Y_i^T$.[1] Each superstar firm earns profits of $\pi_{ij=}(\gamma_{ij}Y_{ij}-\xi_{ij})\cdot UC_i^T$. This region is analogous to the $\epsilon\gamma\leq 1$ region in our baseline model with a single superstar firm.

Unconstrained Duopoly Pricing When competition from traditional firms does not constrain pricing and both superstar firms find it optimal to participate in the market, their optimality conditions in a Cournot duopoly are

$$P_i\left(Y_i^D\right)\left[1-\frac{1}{\epsilon}\left(\frac{Y_{ij}}{Y_i^D}\right)\right]=(1-\gamma_{ij})UC_i^T \text{ for } j\in\{1,2\} \tag{10}$$

which implies market shares that we denote by

$$\lambda_{ij}=\frac{Y_{ij}}{Y_i^D}=\epsilon\left[1-\frac{(1-\gamma_{ij})\,UC_i^T}{P_i\left(Y_i^D\right)}\right] \tag{11}$$

Observing that the two market shares must satisfy $\lambda_{i1}+\lambda_{i2}=1$, we obtain the Cournot duopoly price

$$P_i^D=\frac{2\epsilon}{2\epsilon-1}\left(1-\Sigma_j\,\gamma_{ij}/2\right)\cdot UC_i^T \tag{12}$$

and, substituting the inverse demand function $P_i\left(Y_i,Y\right)$, total output for the duopoly

$$Y_i^D=\left[\frac{2\epsilon}{2\epsilon-1}\left(1-\Sigma_j\,\gamma_{ij}/2\right)UC_i^T\right]^{-\epsilon}\cdot Y$$

Compared to the superstar monopoly solution described in our baseline setup, the duopoly acts as if demand was twice as elastic and charges a price that depends on the average cost savings of the two firms. This captures the standard intuition that prices decline as more firms enter a market in Cournot competition. For example, if both superstar firms have the same cost savings γ_i, they charge half of the markup that a monopoly superstar firm would charge.

We can now establish the condition that guarantees that the duopoly price is not constrained by competition from traditional firms:

[1] The distribution of output between the two superstar firms is indeterminate in this case. One natural way of resolving this is e.g. to assign market shares according to the unconstrained Cournot equilibrium between the two firms, as derived below in equation (11).

Condition 1 (Unconstrained Duopoly Pricing)**.** The duopoly is not constrained by competition from traditional firms if and only if

$$\epsilon \sum_j \gamma_{ij} > 1$$

Proof. The proof follows from re-arranging the inequality $P_i^D < UC_i^T$ using the optimal duopoly pricing condition (12). □

Condition 1 provides an analogous condition to $\epsilon\gamma_{i1} \geq 1$ in our baseline model. When two superstar firms participate in the market, we enter the phase of optimal pricing earlier than under monopoly since the markup charged by duopolistic firms is lower.

Conditions for Existence of Duopoly We now wish to analyze the conditions under which a superstar duopoly will prevail in the market. Profits of each of the two firms in a duopoly would be

$$\pi_{ij}^D = \lambda_{ij} Y_i^D \left[P_i^D - (1-\gamma_{ij}) UC_i^T \right] - \xi_i \text{ for } j \in \{1, 2\}$$

It can be seen that a firm will not find it desirable to enter if either its cost savings γ_{ij} are too low compared to the market price (which will be the case if the other firm has considerably higher cost savings) or if its fixed cost ξ_i are too high.

For simplicity, we consider the case $\xi_i = 0$ in the following. Let us consider a superstar firm with cost savings γ_{i1} and assume a second firm with γ_{i2} that considers whether to enter. The new entrant earns positive profits and finds it desirable to enter if and only if $\pi_{i2}^D > 0$. If pricing behavior in the duopoly equilibrium is constrained by competition from traditional firms, i.e. if Condition 1 is violated, then a duopoly equilibrium is always possible for any $(\gamma_{i1}, \gamma_{i2})$, and both superstar firms charge the price of traditional firms P_i^T.

If Condition 1 is met and the duopoly equilibrium is unconstrained, then substituting the equilibrium duopoly values into the market share function implies a market participation threshold of

$$\gamma_{i2} \geq \hat{\gamma}(\gamma_{i1}) = \frac{\epsilon\gamma_{i1} - 1}{\epsilon - 1}$$

This condition simultaneously guarantees that $\pi_{i2}^D \geq 0$. By symmetry, an analogous expression determines the threshold at which the first superstar firm $i1$ will exit the market.

We summarize the market share dynamics with two superstar firms in the following proposition, which considers a market with an exisiting superstar firm with γ_{i1} and examines what happens as we vary the cost savings parameter γ_{i2} of a potential entrant from zero to one:

Proposition 4 (Market Share Dynamics under Unconstrained Duopoly)**.** *For a given γ_{i1}, as we increase the cost savings γ_{i2}, a potential entrant $i2$*

- *does not enter the market as long as $\gamma_{i2} < \hat{\gamma}(\gamma_{i1})$;*
- *enters the market at $\gamma_{i2} = \hat{\gamma}(\gamma_{i1})$, where $P_i^M = P_i^D$, $Y_i^M = Y_i^D$, and $\lambda_{i2} = 0$;*
- *lowers the market price P_i^D, raises total sector output Y_i^D, and increases its own market share λ_{i2} as γ_{i2} rises further;*
- *takes over the entire market at the point $\gamma_{i1} = \hat{\gamma}(\gamma_{i2})$ so the incumbent superstar firm exits, and monopoly pricing takes over, resulting in steeper declines in price and increases in quantity as γ_{i2} increases further.*

Proof. Most of the proposition is clear from the discussion above. The only thing to verify is that $\gamma_{i2} = \hat{\gamma}(\gamma_{i1})$ is a kink, where $P_i^M = P_i^D$ but $\lim_{\gamma_{i2 \to \hat{\gamma}(\gamma_{i1})^-}} \frac{dP_i}{d\gamma_{i2}} \neq \lim_{\gamma_{i2 \to \hat{\gamma}(\gamma_{i1})^+}} \frac{dP_i}{d\gamma_{i2}}$, but the left hand derivative differs from the right hand derivative. First, note that from equation **??**, we can express

$$\begin{aligned} \frac{P_i^D}{P_i^M} &= \kappa_i \\ &= \frac{(\epsilon - 1)(1 - \gamma_{i1}) + (\epsilon - 1)(1 - \gamma_{i2})}{(\epsilon - 1)(1 - \gamma_{i1}) + \epsilon(1 - \gamma_{i1})} \end{aligned}$$

At $\gamma_{i2} = \hat{\gamma}(\gamma_{i1})$, $\kappa_i = 1$. From our previous discussion, for any $\gamma_{i2} < \hat{\gamma}(\gamma_{i1})$, $\frac{dP_i}{d\gamma_{i2}} = \frac{dP_i^M}{d\gamma_{i2}}$, while for any $\gamma_{i2} > \hat{\gamma}(\gamma_{i1})$, $\frac{dP_i}{d\gamma_{i2}} = \frac{dP_i^D}{d\gamma_{i2}}$. We can explicitly show that $\left|\frac{dP_i^D}{d\gamma_{i2}}\right| < \left|\frac{dP_i^M}{d\gamma_{i2}}\right|$ for all γ_{i2}. By substituting our expression for duopoly price (equation 12) into our expression for λ_{i2} (equation 11), we also see that $\lambda_{i2} = 0$ at $\gamma_{i2} = \hat{\gamma}(\gamma_{i1})$. A symmetric argument can be made for the takeover of monopoly pricing at $\gamma_{i1} = \hat{\gamma}(\gamma_{i2})$. □

Intuitively, a second superstar firm will enter the market if its cost savings are sufficiently high that it can compete with the existing superstar firm. The additional competition pushes down the market price. If the new entrant is sufficiently more productive, she pushes out the existing superstar firm and equilibrium reverts to a monopoly. Accounting for positive costs ξ_{i1} and ξ_{i2} adds additional inequality constraints to the entry and exit conditions of firms without affecting the main intuition of the result.

4.2 Network effects and increasing returns

In this subsection we extend the production technology of superstar firms to exhibit increasing returns from network effects that reduce the marginal cost of each additional unit of output. This provides for a stronger form of increasing returns than our baseline model, in which increasing returns arose due to the fixed costs ξ_i that were spread over a growing number of units of output.

In a nutshell, the insight of this extension is that network effects provide for additional productivity gains but do not change the monopoly markup and factor shares of traditional factor owners. This follows since the optimal monopoly markup is driven by the demand elasticity of consumers not by the specific production technology of firms – although network effects generate a downward-sloping supply curve for superstar firms.

4.3 Elasticity of Substitution

This section consider the case that the elasticity of substitution between different varieties of intermediate goods in final production satisfies $\epsilon \leq 1$ to analyze how superstar firms would act in such an environment. In our baseline model, we assumed that $\epsilon > 1$, which generated an optimal monopoly (gross) markup of $\frac{\epsilon}{\epsilon-1}$. After superstar innovation had generated sufficient cost savings so that they could charge this markup in the face of competition from traditional firms, they passed on any additional cost savings to consumers who expanded demand for the respective variety of intermediate goods to such an extent that the total revenue of superstar firms increased.

When $\epsilon \leq 1$, price reductions in an intermediate variety do not generate sufficent demand so as to increase revenue and profits. In fact, a monopolist who faces the demand function $Y_i = (P_i)^{-\epsilon} Y$ with $\epsilon \leq 1$ would find it optimal to charge a price $P_i \to \infty$ in order to maximize profits. In our setting, competition from traditional firms prevents price increases, but monopolist superstars do not find it optimal to pass on cost savings to their customers even if $\gamma_i \to 1$. This implies that our results in Proposition 1 and its Corollaries 1 and **??** continue to apply, although the inequality $\gamma_i < 1/\epsilon$ is always satisfied by default. For example, when $\epsilon \leq 1$, superstar firms always earn the superstar profit share $\sigma = \gamma_i$.

Whereas the case of $\epsilon > 1$ offered the perspective that digital innovation in the form of increases in γ_i will only temporarily reduce the labor share and ultimately (as soon as $\gamma_i > 1/\epsilon$) lead to growth that is evenly spread across factors, an elasticity of substitution of unity or below raises the dismal specter of all the gains from innovation going to the superstars, with traditional factor owners being clear losers. This would make the competition policies described in Section 3 even more urgent.

4.4 Digital Innovation in Multiple Layers of Production

[to be written up]

4.5 Factor Bias in Digital Innovation

There are two dimensions in which it is natural to extend our baseline model to account for factor bias in digital innovation: (i) the cost ξ_i of innovation activity may use a different mix of factors than traditional production technologies; (ii) the variable cost after a digital innovation MC_i^S may use a different mix of factors. One of the types of factor bias of innovation that has recently received a lot of attention is skill-biased technological change. For illustration, we will discuss an example of case (i) in the following in which we assume that there are two types of labor, skilled labor H and unskilled labor L, of which we assume equal inelastic supplies $H = L = 1$.

[to be typed up]

The clear implication is that digital innovation also has the side effect of raising wages of skilled workers at the expense of unskilled workers. For low levels of digital innovation $\gamma_i < 1/\epsilon$, this implies that unskilled workers are clear losers of digital innovation. Once the level of innovation passes the threshold $\gamma_i \geq 1/\epsilon$, their wages are lifted in tandem with economic growth more generally – unless further digital innovation in additional sectors places further downward pressure on them.

5 Macroeconomic Dynamics

We now embed our model of superstar firms into a dynamic setting in order to analyze the effects of increasing automation for capital accumulation and macroeconomic dynamics.

Consider an infinite horizon discrete time economy with time denoted by $t = 0, 1, \ldots,$ in which production in each sector and period occurs according to either a traditional or a superstar technology, as described in the baseline model of Section 2. We add a subscript t to our notation to denote the time period of each variable. Consumers inelastically supply one unit of labor each period, earning wage W_t, and choose a path of consumption C_t and investment I_t in traditional capital to maximize utility described by the function

$$U = \sum_{t=0}^{\infty} \beta^t u\left(C_t\right)$$

subject to individual period budget and capital accumulation constraints

$$\begin{aligned} C_t + I_t &= W_t + R_t K_t \\ K_{t+1} &= \left(1-\delta\right) K_t + I_t \end{aligned}$$

where $R_t K_t$ is the return on traditional capital in period t and δ is the depreciation rate on traditional capital.

Steady State We compare the steady states of an economy for different levels of digital automation $\gamma_i = \gamma \forall i$ while assuming that $\xi_i = 0 \forall i$. Steady state variables are denoted without the subscipt t. In steady state, the household's Euler equation pins down the equilibrium net interest rate $r = {}^1\!/\!_\beta - 1$ and the associated rental rate of capital $R = r + \delta$. For given γ, the steady state capital share of the economy satisfies

$$RK = \alpha\left(1-\sigma\right) Y = \frac{\alpha\left(1-\sigma\right) A K^{\alpha} L^{1-\alpha}}{1-\gamma} = \alpha A K^{\alpha} \cdot \max\left\{1, \frac{\epsilon - 1}{\epsilon\left(1-\gamma\right)}\right\}$$

Substituting the equilibrium rental rate R, we obtain the steady state level of capital

$$K = \left[\frac{\alpha(1-\sigma)A}{(1-\gamma)R}\right]^{\frac{1}{1-\alpha}} L = \left[\frac{\alpha A}{R}\right]^{\frac{1}{1-\alpha}} \cdot \max\left\{1, \frac{\epsilon - 1}{\epsilon\left(1-\gamma\right)}\right\}^{\frac{1}{1-\alpha}}$$

This implies that the capital stock is unchanged as long as digital innovation remains below the threshold $\gamma < 1/\epsilon$, but then rises in γ in a convex fashion. Output, wages and superstar profits follow immediately from the steady-state level of capital,

$$Y = \frac{AK^{\alpha}L^{1-\alpha}}{1-\gamma} = \frac{A}{1-\gamma} \cdot \left[\frac{\alpha A}{R}\right]^{\frac{\alpha}{1-\alpha}} \cdot \max\left\{1, \frac{\epsilon - 1}{\epsilon\left(1-\gamma\right)}\right\}^{\frac{\alpha}{1-\alpha}}$$

$$w = \left(1-\alpha\right)\left(1-\sigma\right)Y = \frac{\left(1-\alpha\right)\left(1-\sigma\right)AK^{\alpha}L^{1-\alpha}}{1-\gamma} =$$

$$= \left(1-\alpha\right)A\left[\frac{\alpha A}{R}\right]^{\frac{\alpha}{1-\alpha}} \cdot \max\left\{1, \frac{\epsilon-1}{\epsilon\left(1-\gamma\right)}\right\}^{\frac{1}{1-\alpha}}$$

$$\Pi = \sigma Y = \frac{\sigma AK^{\alpha}L^{1-\alpha}}{1-\gamma} = \frac{A}{1-\gamma} \cdot \left[\frac{\alpha A}{R}\right]^{\frac{\alpha}{1-\alpha}} \cdot \min\left\{1/\epsilon, \gamma\right\} \max\left\{1, \frac{\epsilon-1}{\epsilon\left(1-\gamma\right)}\right\}^{\frac{\alpha}{1-\alpha}}$$

For low levels of digital innovation $\gamma < 1/\epsilon$, output rises in a convex manner in γ because of the greater productivity generated by the innovation, but wages remain constant, and all the gains are absorbed by rising superstar profits. After the threshold, output, wages and superstar profits all rise at the same rate, given by the term $\left(\frac{1}{1-\gamma}\right)^{\frac{1}{1-\alpha}}$. These findings are also illustrated in Figure 7, which depicts the comparative statics of steady state output as a function of digital automation γ, split into the three components capital share, labor share, and superstar profit share.

Transitional Dynamics We now examine the dynamics of the system as it converges to a new steady state. We assume for simplicity that the economy starts out without superstar technologies and experiences a shock that raises digital innovation to $\gamma_i = \gamma \forall i$ in period 0.

For low levels of digital innovation $\gamma < 1/\epsilon$, the dynamics are simple: since all the benefits of the innovation are captured by superstars, output rises but the capital stock and wages remain constant. This implies that there are no transitional dynamics and the economy jumps immediately to the new steady state.

If digital innovation rises above the threshold $\gamma > 1/\epsilon$, the capital stock will rise to a higher level, and the transition is determined by the Euler equation

$$\frac{u'(c_{t+1})}{u'(c_t)} = \frac{R_t(K_t) + 1 - \delta}{\beta}$$

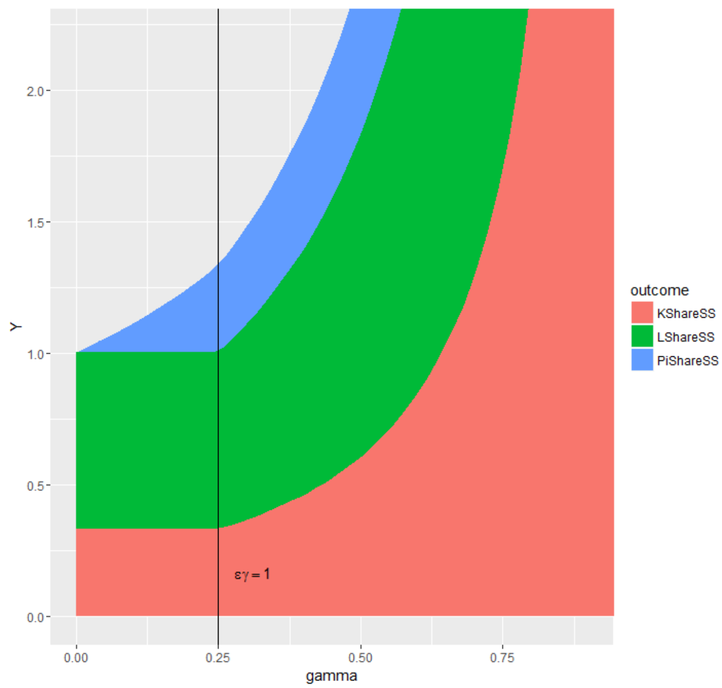

Figure 7: Comparative statics of steady state as a function of automation

where $R_t = \frac{\epsilon-1}{\epsilon}\frac{\alpha A}{1-\gamma}K_t^{\alpha}$. Since $\frac{dR_t}{d\gamma} > 0$, a positive shock to γ results in lower consumption and higher saving on impact, i.e. c_0 jumps downwards at time 0, but the system evolves in a smooth way thereafter to the new steady state of higher capital stock, higher wages, and higher consumption.

6 Conclusion

Our paper describes how the introduction of digital technologies leads to winner-takes-all markets and the creation of superstars. Digital innovation imposes up-front fixed costs that allow firms to reduce the marginal cost of serving additional customers. Since the digital innovations typically come with a considerable extent of excludability, they also confer monopoly power to the innovators, enabling them to turn into superstars in the market that they are serving. We argue that this represents one of the fundamental driving forces behind the rise in inequality in recent decades.

We show that increasing digital automation entails a complex trade-off: at first, automation lowers production costs but induces superstar firms to absorb the cost savings via higher markups and to extract increasing monopoly rents whereas the labor share in the economy declines. Once the optimal markup is reached, further progress in automation is passed on to consumers via cost savings, leading to economic growth with a constant (but depressed) labor share and constant monopoly profit share accruing to superstars. Although monopoly rents for superstars support their investment in digital technologies, the overall level of such rents is socially excessive.

References

Alvarez-Cuadrado, F., Long, N. V., and Poschke, M. (2014). Capital-Labor Substitution, Structural Change and the Labor Income Share. CESifo Working Paper Series 4600, CESifo Group Munich.

Autor, D., Dorn, D., Katz, L. F., Patterson, C., and Reenen, J. V. (2017). The Fall of the Labor Share and the Rise of Superstar Firms. NBER Working Papers 23396, National Bureau of Economic Research, Inc.

Autor, D. H. and Dorn, D. (2013). The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market. *American Economic Review*, 103(5):1553–1597.

Bakija, J., Cole, A., and Heim, B. (2012). Jobs and Income Growth of Top Earners and the Causes of Changing Income Inequality: Evidence from U.S. Tax Return Data. Department of Economics Working Papers 2010-22, Department of Economics, Williams College.

Brynjolfsson, E., Hu, Y. J., and Smith, M. D. (2010). Research Commentary — Long Tails vs. Superstars: The Effect of Information Technology on Product Variety and Sales Concentration Patterns. *Information Systems Research*, 21(4):736–747.

Elsby, M., Hobijn, B., and Sahin, A. (2013). On the importance of the participation margin for market fluctuations. Working Paper Series 2013-05, Federal Reserve Bank of San Francisco.

Gabaix, X. and Landier, A. (2008). Why has CEO Pay Increased So Much? *The Quarterly Journal of Economics*, 123(1):49–100.

Garicano, L. and Rossi-Hansberg, E. (2006). Organization and Inequality in a Knowledge Economy. *The Quarterly Journal of Economics*, 121(4):1383–1435.

Kaplan, S. N. and Rauh, J. (2010). Wall Street and Main Street: What Contributes to the Rise in the Highest Incomes? *Review of Financial Studies*, 23(3):1004–1050.

Karabarbounis, L. and Neiman, B. (2013). The Global Decline of the Labor Share. NBER Working Papers 19136, National Bureau of Economic Research, Inc.

Mueller, H. M., Ouimet, P. P., and Simintzi, E. (2015). Wage inequality and firm growth. Working Paper 20876, National Bureau of Economic Research.

Noe, T. and Parker, G. (2005). Winner Take All: Competition, Strategy, and the Structure of Returns in the Internet Economy. *Journal of Economics & Management Strategy*, 14(1):141–164.

Piketty, T. and Saez, E. (2001). Income Inequality in the United States, 1913-1998 (series updated to 2000 available). NBER Working Papers 8467, National Bureau of Economic Research, Inc.

Rosen, S. (1981). The Economics of Superstars. *American Economic Review*, 71(5):845–858.