Automation and Unemployment: Help is on the Way

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Main Goal and Main Result

- This paper examines the effect of automation on unemployment.
- It combines a task-based model of automation (like Zeira, 1998) with an expanding variety model (like Romer 1990), due to both theoretical and empirical considerations.
- We assume that the share of labor does not converge to zero in the long-run.
- We then show that although automation increases unemployment, this additional unemployment diminishes over time and converges to zero as time goes to infinity.

Three Main Assumptions

- The first is that producers freely choose the tasks for the production of the final good.
- The second assumption is that new automation innovations are invented only as long as they are adopted by producers.
- The third and main assumption is that although the share of labor in output can decline, it does not go all the way to zero. This assumption fits the stylized facts of economic growth.
- It is also reasonable theoretically, as it rules out the case of convergence to production by machines only.

Creation of New Labor Tasks

- Our model does not assume that new tasks arrive at some positive rate. It only allows this possibility.
- The model shows that such tasks are created if automation is not bounded.
- This is also supported by data on job titles. According to the National Occupational Classification of Canada, there were 35,000 job titles in 2016, with an increase of 204 new job titles since 2011.
- It also makes sense that automation leads to creation of new tasks, to manage, run, produce and maintain the machines.

The Public Discourse: Fear

- The issue of unemployment due to mechanization occupied the public discourse since the industrial revolution:

- Textile artisans led the Luddites' rebellion of 1811-1817 and it took a large British army of 12,000 soldiers, to oppress it.
- In 1852 the French mathematician and engineer Charles Dupin wrote: "By superseding labor the country is depopulated and filled with machines."
- On February 1928, Evan Clark wrote on "March of the Machine Makes Idle Hands."
- Recently, there is growing fear of the effect of IT and AI on jobs.

The Public Discourse: Optimism

- All this time others expressed optimism about the effects of automation on employment:

- In response to Dupin, *The Economist* wrote in 1852: “The reverse is the fact. England is not depopulated and it is by using and employing more and more machinery, that her people are nourished and increase in numbers as well as in wealth.”

- In his famous essay “Economic Possibilities for our Grandchildren” from 1930, Keynes claimed that automation eliminates jobs, but also increases leisure, so total employment rises.

Brief Survey of Line of Research

- First model of production by tasks is Champernowne (1963). Zeira (1998) applied to a general equilibrium framework, focusing on the role of wages in adopting new mechanized technologies.

- Zeira (1998) had some limitations, like convergence of labor share to zero and no Solow residuals.

- Recently, Acemoglu and Restrepo (2017a, 2017b, 2018a, 2018b) and Aghion, Jones and Jones (2017) extended the task model in different ways.

- This paper extends it by combining it with Romer (1990) and examines the short-run effect on unemployment.

The Model: Production

- Production of the final good: $$Y_t = \left[\int_0^{T_t} x_t(j)^\theta \, dj \right]^{\frac{1}{\theta}}. \qquad \theta < 1$$

- Tasks, or intermediate goods, between 0 and *M* are performed by machines. Tasks between *M* and *T* are performed by labor.

- Each unit of labor produces one unit of the task. Each unit of an automated task *j* is performed by a machine of size *k*(*j*). This is an increasing function. Capital depreciates within one period of time.

- We assume that $\theta > 0$ and we show below that it is required by our assumption that producers decide on which tasks to use.

The Model: Technical Change

- Number of mechanized tasks M and total number of tasks T are non-decreasing over time and these are the two types of technical change in the model: automation and creation of new labor tasks.

- We do not assume that T actually increases over time, and it will be a result of the model in the main case.

- We assume that both are exogenous and determined outside the model.

- We impose only one assumption on change of M, that automation is not invented if it is not adopted by producers.

The Model: Unemployment

- Infinite horizon workers supply one unit of labor each period. Total measure of workers is 1.

- If their task is mechanized in period t, they do not work in this period, and are unemployed during t. They search for work, and then find a new job from $t + 1$ on.

- Hence, unemployment is due to automation. The appendix examines an additional type of unemployment, due to mismatch. We find that the main results are the same and that unemployment due to automation declines to zero.

- The economy has free capital mobility. Global interest rate is r.

Equilibrium: FOC and Restriction 1

- The profit of producers is:

$$\left[\int_0^{T_t} x_t(j)^\theta dj\right]^{\frac{1}{\theta}} - \int_0^{T_t} p_t(j)x_t(j)dj$$

- The marginal profit with respect to the number of tasks T is equal to:

$$\frac{1}{\theta}Y_t^{1-\theta}x_t(T)^\theta - p_t(T)x_t(T)$$

- Hence, if θ is negative, marginal profit is negative and producers do not use any task. This justifies our assumption: $\theta > 0$.

Equilibrium: FOC and Number of Tasks

- The FOC with respect to the quantity of each task is:

$$x_t(j) = Y_t \cdot p_t(j)^{\frac{-1}{1-\theta}}$$

- Substituting this FOC in the marginal profit of *T* we get:

$$\frac{1}{\theta} Y_t^{1-\theta} x_t(T)^{\theta} - p_t(T) x_t(T) = \left(\frac{1}{\theta} - 1 \right) Y_t \, p_t(T)^{\frac{-\theta}{1-\theta}} > 0.$$

- Hence, producers use all tasks, namely all intermediate goods and hence every invented labor task is used in production..

Equilibrium: Goods Equilibrium Condition

- Since the FOC with respect to the quantity of each task j is:

$$x_t(j) = Y_t \cdot p_t(j)^{\frac{-1}{1-\theta}}$$

- We next substitute it in the production function of the final good. It can be shown that the prices of intermediate goods satisfy:

$$\int_0^{T_t} p_t(j)^{\frac{-\theta}{1-\theta}} dj = 1$$

- This is an equilibrium condition in the goods markets. We next substitute in this equation the supply prices of the intermediate goods.

Equilibrium: Markets for Tasks

- Prices of automated intermediate goods: $p_t(j) = p(j) = Rk(j)$

- Prices of labor produced goods: $p_t(j) = w_t$

- Substituting in the equilibrium condition:

$$R^{\frac{-\theta}{1-\theta}} \int_0^{M_t} k(j)^{\frac{-\theta}{1-\theta}} dj + \int_{M_t}^{T_t} w_t^{\frac{-\theta}{1-\theta}} dj = 1$$

- This condition enables us to find the equilibrium wage rate.

Equilibrium: Wage Determination

- We define a function φ of automation M:

$$\varphi(M) = R^{\frac{-\theta}{1-\theta}} \int_0^M k(j)^{\frac{-\theta}{1-\theta}} dj \leq 1$$

- This function φ is increasing and concave. The equilibrium wage rate is:

$$w_t = \left[\frac{T_t - M_t}{1 - \varphi(M_t)} \right]^{\frac{1-\theta}{\theta}}$$

- Hence, the wage depends positively on the number of labor tasks. Intuition: more tasks imply less workers in each task, so their marginal productivity is higher and so is the wage.

Equilibrium: The Share of Labor

- From the FOC we get: $$Y_t = x_t(j) w_t^{\frac{1}{1-\theta}} = \frac{E_t}{T_t - M_t} w_t^{\frac{1}{1-\theta}}$$

- Hence the share of labor is: $$\frac{w_t E_t}{Y_t} = \left(T_t - M_t\right) w_t^{\frac{-\theta}{1-\theta}} = 1 - \varphi(M_t)$$

- Note that the share of labor is negatively related to wages. Intuition: as *w* rises, *x* is reduced by more than price, so labor income declines and so does the share of labor in output.

Equilibrium: Adoption of Automation

- Automation technology is adopted only if wages exceed costs of machinery. Hence, new automation technologies are adopted as long as:

$$w_t \geq Rk(M_t)$$

- Using the value of wages we get:

$$T_t - M_t \geq k(M_t)^{\frac{\theta}{1-\theta}} R^{\frac{\theta}{1-\theta}} \left[1-\varphi(M_t)\right] = \frac{1-\varphi(M_t)}{\varphi'(M_t)}$$

- This condition means that the number of new tasks should increase at a high rate, as the numerator is positive, while the denominator goes down to zero.

Dynamics: Bound on Automation

- The adoption of automation condition can be written as:

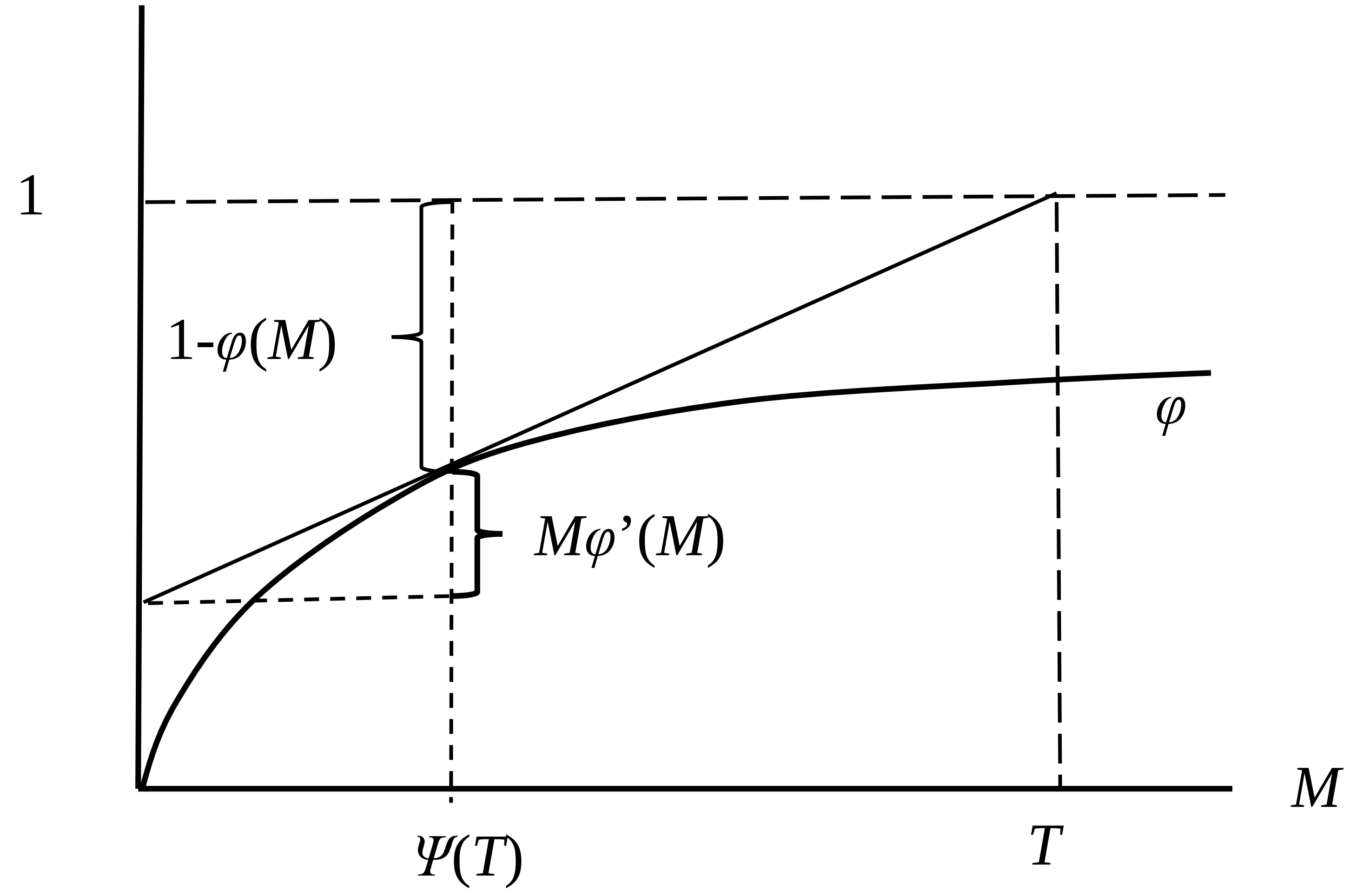
$$T_t \geq M_t + \frac{1-\varphi(M_t)}{\varphi'(M_t)} = \frac{M_t\varphi'(M_t)+1-\varphi(M_t)}{\varphi'(M_t)}$$

- The RHS of this equation is increasing in *M* and hence it determines a maximum level of automation *M* that satisfies it.

- We denote this level as a function of number of tasks *T*: $\psi(T_t)$

- According to our assumption, automation is bounded by this level.

Dynamics: Determination of ψ



Dynamics: Bounded and Unbounded *M*

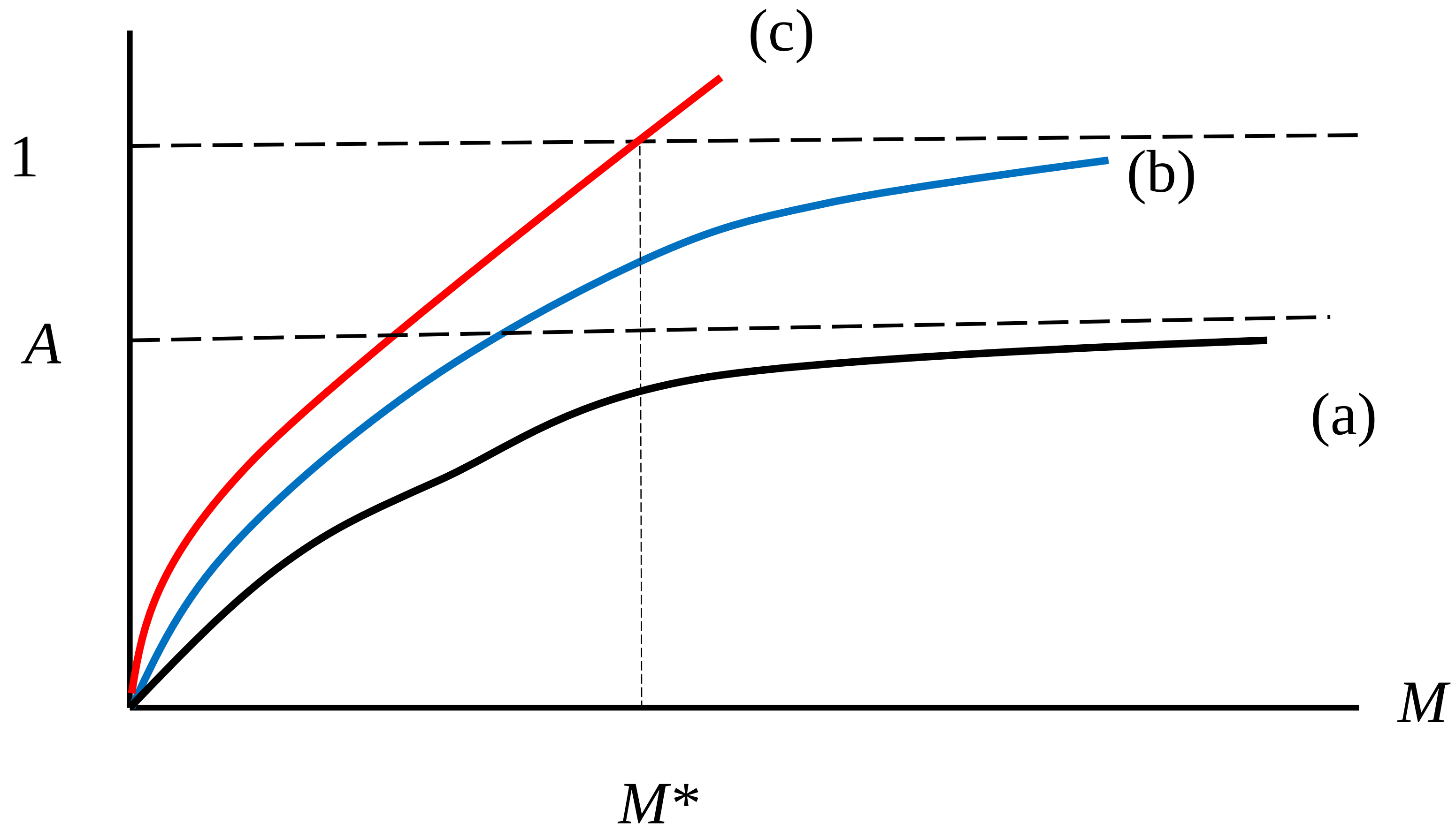
- There are two long-run cases of automation. One is that it is bounded by a finite level M^* and the other is that it continues unbounded.

- Clearly, the adoption condition implies that if M is unbounded, then so is the number of tasks. We show below that it is not only unbounded, but it grows faster than M.

- The case when M is bounded implies that new automation converges to zero over time and hence so does the rate of technological unemployment.

- The more difficult case is therefore the case of unbounded M.

Dynamics: Shape of φ – Three Cases



Dynamics: Share of Labor Positive in the LR

- We next present our main assumption:

- The share of labor in the economy does not converge to zero. Formally, if:

$$A = \sup\left\{\varphi(M_t) : t < \infty\right\}$$

- Then we assume that $A < 1$.

- In terms of the three cases this assumption means that either case (a) holds, or in cases (b) or (c) automation is bounded, so that $\varphi(M)$ does not pass A.

Dynamics: Stability of the Share of Labor

- Hence, as automation goes on, the share of labor declines from 1 to $1 - A$, which is a positive number.

- As M rises the changes in the share of labor become smaller and it is therefore stable in the long-run, as observed empirically.

- Interestingly, if capital is used in production by labor as well, for example for structures, this result becomes even stronger.

- We show in an appendix that in this case the share of labor is lower than 1 before mechanization, while as M progresses, it still converges to $1 - A$.

Dynamics: The Rate of Automation in the LR

- <u>Proposition 1:</u> In the long-run: $\frac{\varphi'(M_{t-1})\Delta M_t}{1-\varphi(M_{t-1})} \xrightarrow[t\to\infty]{} 0$

- Proof: Note that 1- $\varphi(M)$ converges to $1 - A$ and hence its rate of growth goes to zero. This rate is:

$$\Delta \ln\left[1-\varphi(M_t)\right] = \frac{-\varphi'(M_{t-1})\Delta M_t}{1-\varphi(M_{t-1})}$$

- This proposition is important since the condition for adoption of automation is equivalent to:

$$\frac{1}{T_t - M_t} \leq \frac{\varphi'(M_t)}{1-\varphi(M_t)}$$

Dynamics: Race of Technical Changes

- From the condition to technology adoption we also get:

$$\frac{M_t}{T_t - M_t} \leq \frac{M_t \varphi'(M_t)}{1 - \varphi(M_t)}$$

- Proposition 2: If M_t is unbounded, the number of labor jobs $T_t - M_t$ increases to infinity faster than M_t.

$$\frac{M}{T - M} \leq \frac{M \varphi'(M)}{1 - \varphi(M)} \xrightarrow[M \to \infty]{} 0$$

- Proof: The numerator converges to zero, while the denominator converges to $1 - A$, which is positive.

Economic Growth

- Output per worker is:

$$y_t = \frac{Y_t}{E_t} = \frac{w_t}{1-\varphi(M_t)} = \frac{\left(T_t - M_t\right)^{\frac{1-\theta}{\theta}}}{\left[1-\varphi(M_t)\right]^{\frac{1}{\theta}}}$$

- Hence the rate of growth of output per worker is:

$$\Delta \ln y_t = \frac{1-\theta}{\theta}\Delta \ln\left(T_t - M_t\right) + \frac{1}{\theta}\frac{\varphi'(M_{t-1})\Delta M_t}{1-\varphi(M_{t-1})}$$

- We, therefore, see that the rate of growth is a weighted sum of the rate of expansion of tasks and the rate of growth which is a result of automation.

Economic Growth: The Long-Run

- As shown above, in the long-run: $$\frac{\varphi'(M_{t-1})\Delta M_t}{1-\varphi(M_{t-1})} \xrightarrow[t\to\infty]{} 0$$
- Hence, the long-run rate of growth is: $$\Delta \ln y_t \cong \frac{1-\theta}{\theta} \Delta \ln\left(T_t - M_t\right)$$
- The long-run growth is determined by the expanding variety part of the model, while the shares of factors are determined by the task part.
- Another conclusion is that if M is bounded, then growth is bounded as well.

Economic Growth: The Solow Residual

- The capital labor ratio is:

$$\frac{K_t}{E_t} = \frac{y_t}{R}\varphi(M_t)$$

- The Solow Residual is:

$$SR_t = \Delta \ln y_t - \varphi(M_t)\Delta \ln\left(\frac{K_t}{E_t}\right)$$

- Hence, it is equal to:

$$SR_t = \left[1-\varphi(M_t)\right]\frac{1-\theta}{\theta}\Delta \ln(T_t - M_t) + \frac{1-\theta}{\theta}\left[\varphi'(M_{t-1})M_{t-1}\right]\frac{\Delta M_t}{M_{t-1}}$$

- It follows that the Solow Residual is positive, and in the long-run it is the share of labor times the rate of growth of output per worker, which fits facts.

Economic Growth: Capital and Labor

- We can substitute the quantities of the intermediate goods and get the following production function by capital and labor:

$$Y_t = \left[(T_t - M_t)^{1-\theta} E_t^{\theta} + \varphi (M_t)^{1-\theta} R^{\theta} K_t^{\theta} \right]^{\frac{1}{\theta}}$$

- The coefficients of labor and capital do not depend directly on the factors of production, but they are related to it through the wage rate. As a result the elasticity of substitution is not $1/(1-\theta)$, but rather close to 1.

- Note, that the coefficient of capital is bounded, while the coefficient of labor is growing unboundedly. Hence, technical change is labor augmenting.

The Rate of Unemployment

- If task *j* becomes mechanized in period *t* the number of people who become unemployed as a result are those who worked there in period *t* – 1.

- Hence unemployment due to automation over all automated tasks is:

$$U_t^A = \int_{M_{t-1}}^{M_t} l_{t-1}(j)dj$$

- We next calculate the number of workers in each job. Note that as all tasks face the same price and the same wage rate, they hire the same amount of workers.

The Rate of Unemployment in the Long-Run

- Employment in t -1 for each task is: $$l_{t-1}(j) = \frac{E_{t-1}}{T_{t-1} - M_{t-1}}$$

- Hence: $$U_t^A = \frac{E_{t-1}\Delta M_t}{T_{t-1} - M_{t-1}} \leq \frac{\Delta M_t}{T_{t-1} - M_{t-1}} \leq \frac{\Delta M_t \varphi'(M_{t-1})}{1 - \varphi(M_{t-1})}$$

- Using Proposition 2 we get:

- <u>Theorem 1:</u> Unemployment due to automation converges to zero over time.

The Rate of Unemployment: Discussion

- The intuition behind this surprising result is related to adoption of automation, which requires that wages should rise significantly above the cost of machines.

- Wages rise either if the share of labor goes to zero, or if the number of labor tasks rises fast. Then labor in each task declines, and marginal productivity rises.

- Hence, our assumption that the share of labor does not go to zero is crucial.

- The main result holds also when we add unemployment due to mismatch.

Balanced Growth Path

- We next turn to describe a specific case of balanced growth. Assume that the function *k* is:

$$k(j) = a(1+j)^{\alpha}$$

- Where the coefficients satisfy: $\alpha > (1-\theta)/\theta$

- Assume that both automation and the number of jobs grow at a constant rate:

$$\frac{\Delta M}{M} = g_M \qquad \frac{\Delta T}{T} = g_T$$

Balanced Growth Path: Rate of Growth

- The condition of technology adoption implies: $$g_T \geq \frac{\alpha\theta}{1-\theta} g_M > g_M$$

- Assume for simplicity that: $$g_T = \frac{\alpha\theta}{1-\theta} g_M$$

- Then:

$$\Delta \ln y = \frac{1-\theta}{\theta}\Delta \ln(T-M) + \frac{1}{\theta}\frac{M(aR)^{\frac{-\theta}{1-\theta}}}{(1-A)(1+M)^{\frac{\alpha\theta}{1-\theta}} + A(1+M)} g_M \xrightarrow[M\to\infty]{} \frac{1-\theta}{\theta} g_T$$

Balanced Growth Path: Unemployment

- When the economy follows the balanced growth path, the rate of unemployment due to automation is bounded as follows:

$$U_t^A \le \frac{\Delta M_t}{M_{t-1}} \frac{\varphi'(M_t)M_{t-1}}{1-\varphi(M_t)} = g_M \frac{(aR)^{\frac{-\theta}{1-\theta}}(1+M_t)^{\frac{1-\theta-\alpha\theta}{1-\theta}}}{1-\left(aR\right)^{\frac{-\theta}{1-\theta}} \frac{1-\theta}{\theta+\alpha\theta-1}\left[1-\left(1+M_t\right)^{\frac{1-\theta-\alpha\theta}{1-\theta}}\right]}$$

- This bound converges to zero as *M* goes to infinity. Hence, the rate of unemployment due to automation converges to zero.

Better Machines

- One possible critique on the model is that technical change can also make machines better and cost less.

- In that case we need that wages would not rise as much. That means that less jobs need to be created.

$$\varphi(M) = \left(aR\right)^{\frac{-\theta}{1-\theta}} \frac{1-\theta}{\theta+\alpha\theta-1}\left[1-\left(1+M\right)^{\frac{1-\theta-\alpha\theta}{1-\theta}}\right]$$

- But this critique does not fit our model. The reason is that if the cost of machines decline, in the case of the balanced growth path if *a* declines, the share of labor declines continuously. Then it might reach zero fast.

Disappearing Tasks

- Another issue is that when new jobs are added, automated jobs disappear, as assumed in the papers by Acemoglu and Respero.

- This is impossible in this model. Since θ is positive, due to restriction 1, producers use all tasks that were invented in the past. Also note that it makes sense intuitively, as we still grow wheat, barley, olives, and write poems, and put theater shows, etc.

- The possibility of non-falling unemployment is due to disappearing tasks and rising labor productivity over tasks, together. The second assumption alone does not change our main result, as shown in an Appendix.

Skills: Jobs Creation

- Finally, assume that there are two skill levels, high and low. Assume for simplicity that the numbers of high and low skilled are constant over time, at H and L respectively.

- Assume also that jobs are skill specific. There is an indicator function S that receives 1 at a high skill job and 0 at a low skill job.

- The density of skill between x and y is:

$$d(x, y) = \frac{1}{y - x} \int_x^y S(j)dj$$

- Assume for simplicity that it is constant.

Skills: With Automation

- Assuming that there is no unemployment in the economy:

$$\left(\frac{w_t^H}{w_t^L}\right)^{\frac{1}{1-\theta}} = \frac{d}{1-d}\frac{L}{H}$$

- Calculating the wages for the two skill levels we get:

$$\text{share of labor in } t = \frac{w_t^H H + w_t^L L}{Y_t} = 1-\varphi(M_t)$$

- Think of SBTC as a rise in *d*. It increases the skill premium. But it has a very different meaning and is not related to automation. It does not have any effect on the share of labor. Hence, this cannot be related to SBTC.

Summary

- This model predicts that unemployment due to automation will converge in the future to zero.

- These are great news, but they should be taken with many grains of salt.

- Economic models should be used to help us to understand economic mechanisms, rather then make predictions about the future (Yogi Berra…).

- Hence this model should be interpreted as showing the importance of the growing number of jobs as a force that reduces the effect of losses of jobs to automation.