The Race Between Man and Machine: Implications of Technology for Growth, Factor Shares and Employment

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The Life and Work of Gary Becker
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Recent concerns about the implications of technology:

- The replacement of labor by machines in various tasks has reduced wage growth (Autor, Levy and Murnane, 2013, Acemoglu and Autor, 2011) and will create (or has already created) nonemployment (e.g., Brynjolfsson and McAfee, 2012).
- Technological change, or the associated accumulation of capital, is reducing the share of labor in national income (e.g., Karabarbounis and Neiman, 2014, Piketty and Zucman, 2014, Oberfield and Raval, 2014).

But we lack a conceptual framework that can elucidate how technological change, which has always replaced some labor-intensive tasks by capital, has coexisted with steady wage growth, roughly constant unemployment and factor shares in the past, and what aspects of new technologies are impacting these economic outcomes today.
This Paper

- A framework to study the joint evolution of technology, factor shares and employment.
- **Main new ingredient**: in addition to capital simplifying and replacing tasks previously performed by labor, new more complex tasks relying on labor are created.
- E.g.:
  - the replacement of the stagecoach by the railroad, of the sailboat by the steamboat or of dockworkers by cranes are examples of capital-labor substitution, but these went hand-in-hand with the creation of several entirely new labor-intensive tasks, including a new class of engineers, new types of managers and financiers, machinists, repairmen, conductors, and so on;
  - today, as computers and machines replace labor, we are also creating new design tasks ranging from engineering tasks based on new machines to programming and apps design.
This new ingredient is embedded in a dynamic model in which two types of innovations create different and countervailing forces:

1. Labor-replacing innovations enable capital to replace previously labor-intensive tasks.
2. Labor-intensive innovations create new, more complex versions of existing tasks (typically replacing previously capital-intensive tasks).

With this structure, growth will take place due to productivity upgrading of a fixed set of tasks as well as from the substitution of capital for labor.

This setup is embedded in a dynamic economy with *endogenous*, *directed technological change*, which highlights important self-correcting market forces.
The framework incorporates features from several different types of models:

Outline

- Motivating Evidence
- Static Model
- Comparative Statics
- The Structure of Balanced Growth Path
- Dynamic Model with Directed Technological Change
- Welfare Analysis
- Extensions
- Conclusions and Future Work
Motivating Evidence: Novel jobs.

Figure: Employment growth and share of novel jobs (from Lin 2011). The additional job creation in occupational groups with novel jobs accounts for about 50% of total employment growth between 1980 and 2008.
There is a unique final good $Y$ produced by combining a continuum of tasks $y(i)$, with $i \in [N - 1, N]$.

$$Y = \left( \int_{N-1}^{N} y(i) \frac{\sigma - 1}{\sigma} \, di \right)^{\frac{\sigma}{\sigma - 1}} , \sigma \in (0, \infty) : \text{elasticity of substitution.}$$

Set the resulting ideal price index as numeraire.

The range $N - 1$ to $N$ implies that the set of tasks is constant, but older tasks might be replaced by new (more complex and more productive) versions thereof.

Namely, an increase in $N$ adds a new task at the top while simultaneously replacing one at the bottom.
Static Model: Intermediates

- Each task is produced by combining capital or labor with an intermediate good $q(i)$ embodying technology.

- In preparation for the model with endogenous technology, we assume that each intermediate is supplied by a monopolist, which can produce one unit of intermediate at the cost of $\mu \psi$ units of the final good (where $\mu \in (0, 1)$).

- There is also fringe of competitive imitators that can copy the technology for each intermediate and produce it at the cost of $\psi$ units of the final good.

- We assume that $\mu$ is such that the unconstrained monopoly price is greater than $\psi$.

- This implies that in the pricing game between the monopolist and the fringe, there will be a limit price equilibrium, and each unit of every intermediate will be sold at a constant price $\psi$. 
Tasks with $i \leq I$ are technologically **automated**, and can be produced with labor or capital according to

$$y(i) = B \left[ \eta q(i) \frac{\zeta - 1}{\zeta} + (1 - \eta) (k(i) + \gamma(i)l(i)) \frac{\zeta - 1}{\zeta} \right]^{\frac{\zeta}{\zeta - 1}}$$

Tasks with $i > I$ are not technologically automated yet, and can only be produced with labor:

$$y(i) = B \left[ \eta q(i) \frac{\zeta - 1}{\zeta} + (1 - \eta) (\gamma(i)l(i)) \frac{\zeta - 1}{\zeta} \right]^{\frac{\zeta}{\zeta - 1}}.$$

We assume $\gamma(i)$ is strictly increasing, so labor has a comparative advantage in more complex tasks (in fact, it is more productive in these tasks), and normalize $B \equiv (1 - \eta)^{\zeta} / (1 - \zeta)$. 
In the static model, we take capital to be fixed at $K$ and rented at a price $r$ (determined endogenously).

Total labor used is given by

$$L^s \left( \frac{W}{rK} \right),$$

where $L^s$ is a weakly increasing function, and $W$ is the wage rate.

- This is a reduced form for many different models of labor supply and quasi-labor supply behavior.
- It is derived from an efficiency wage model in the Appendix.
- In Acemoglu and Restrepo (2015), we derive this curve endogenously as the equilibrium representation in a search-matching model.
Equilibrium: Task Prices

- Let $c^u(\cdot)$ be the unit cost of production for a task as a function of the price of the relevant factor.
- Then, equilibrium task prices will be given by

$$
 p(i) = \begin{cases} 
 c^u \left( \min \left\{ r, \frac{W}{\gamma(i)} \right\} \right) \equiv \left[ \psi^{1-\zeta} + \left( \frac{1-\eta}{\eta} \right)^{\zeta} \min \left\{ r, \frac{W}{\gamma(i)} \right\} \right]^{1-\zeta} \frac{1}{1-\zeta} & \text{if } i \leq I, \\
 c^u \left( \frac{W}{\gamma(i)} \right) \equiv \left[ \psi^{1-\zeta} + \left( \frac{1-\eta}{\eta} \right)^{\zeta} \left( \frac{W}{\gamma(i)} \right)^{1-\zeta} \right]^{1-\zeta} \frac{1}{1-\zeta} & \text{if } i > I, 
\end{cases}
$$

(1)

- Given factor prices, firms are indifferent between using capital and labor in task $\tilde{I}$:

$$
 \frac{W}{r} = \gamma(\tilde{I}).
$$

(2)

- Tasks with $i \leq I^* \equiv \min\{I, \tilde{I}\}$ will be automated and produced with capital, and tasks with $i > I^*$ will be produced with labor.
Equilibrium: Task Space

Tasks performed by capital  Labor-intensive tasks  New tasks

Replaced tasks

Tasks performed by capital  Labor-intensive tasks  Automated tasks
Equilibrium: Market Clearing

- Factor demands in capital- and labor-intensive tasks are
  \[ k(i) = YBc^u(r)\zeta^{-\sigma} r^{-\zeta} \text{ if } i \leq I^* \]
  and
  \[ l(i) = \gamma(i)\zeta^{-1} YBc^u \left( \frac{W}{\gamma(i)} \right) \zeta^{-\sigma} W^{-\zeta} \text{ if } i > I^*. \]

- Thus, factor market clearing conditions can be written as
  \[ Y \left( \min\{l, \tilde{l}\} - N + 1 \right) Bc^u(r)\zeta^{-\sigma} r^{-\zeta} di = K, \quad (3) \]
  and
  \[ Y \int_{\min\{l, \tilde{l}\}}^{N} \gamma(i)\zeta^{-1} Bc^u \left( \frac{W}{\gamma(i)} \right) \zeta^{-\sigma} W^{-\zeta} di = L^s \left( \frac{W}{rK} \right). \quad (4) \]
Proposition (Equilibrium in the static model)

For any range of tasks \([N - 1, N]\), automation \(l \in (N - 1, N]\), and capital \(K\), there exists a unique equilibrium characterized by factor prices, \(W\) and \(r\), and threshold tasks, \(\tilde{l}\) and \(l^*\), such that: (i) \(\tilde{l}\) is determined by equation (2) and \(l^* = \min\{l, \tilde{l}\}\); (ii) all tasks \(i \leq l^*\) are produced using capital and all tasks \(i > l^*\) are produced using labor; (iii) capital and labor market clearing conditions, equations (3) and (4), are satisfied; and (iii) factor prices satisfy:

\[
(l^* - N + 1)c^u(r)^{1-\sigma} + \int_{l^*}^{N} c^u \left( \frac{W}{\gamma(i)} \right)^{1-\sigma} di = 1. \tag{5}
\]
Let $\omega \equiv \frac{W}{rK}$.

**Figure**: Graphical representation of the equilibrium. Case with $I^* < I$. 
Diagrammatic Representation

Figure: Graphical representation of the equilibrium. Case with $I^* = I$. 

$I^* = \min \{ I, \tilde{I} \}$

$\gamma(\tilde{I}) = \omega K$

$\omega = \omega(I^*, N, K)$

$\omega$
Comparative Statics

**Proposition (Comparative statics if $l^* = l < \tilde{l}$)**

We have:

$$\frac{d \ln \omega}{dl} = \frac{d \ln (W / r)}{dl} < 0, \quad \frac{d \ln \omega}{dN} = \frac{d \ln (W / r)}{dN} > 0$$

and

$$\frac{d \ln \omega}{d \ln K} + 1 = \frac{d \ln (W / r)}{d \ln K} = \frac{1}{\sigma_{SR}} > 0.$$

- Here, $\sigma_{SR} \in [0, \infty)$ is the short-run elasticity of substitution between labor and capital, which is a weighted average of $\sigma$ and $\zeta$.
- $\frac{d \ln W}{dl} < 0$ if $\sigma_{SR}$ is sufficiently large, and $\frac{d \ln W}{dl} \geq 0$ otherwise.
Comparative Statics (continued)

Proposition (Comparative statics if $I^* = \tilde{I} < I$)

Let $\varepsilon \equiv \frac{d \ln \gamma(I)}{dI} > 0$ be the semi-elasticity of the comparative advantage schedule, so that $dl^* = \frac{1}{\varepsilon} d \ln \left( \frac{W}{r} \right)$. Then:

$$
\frac{d \ln \omega}{dl} = \frac{d \ln \left( \frac{W}{r} \right)}{dl} = 0, \quad \frac{d \ln \omega}{dN} = \frac{d \ln \left( \frac{W}{r} \right)}{dN} > 0 \text{ and }
$$

$$
\frac{d \ln \omega}{d \ln K} + 1 = \frac{d \ln \left( \frac{W}{r} \right)}{d \ln K} = \frac{1}{\sigma_{MR}} > 0,
$$

where $\sigma_{MR}$ is the medium-run aggregate elasticity of substitution

$$
\sigma_{MR} = \sigma_{SR} \left( 1 - \frac{1}{\varepsilon} \frac{\partial \ln \left( \frac{W}{r} \right)}{\partial l^*} \right) > \sigma_{SR}.
$$

Also, $\frac{d \ln W}{dl} < 0$ if $\sigma_{MR}$ is sufficiently large, and $\frac{d \ln W}{dl} \geq 0$ otherwise.
Comparative Statics: Interpretation

- New result relative to the standard factor-augmenting technology framework: technological advances can reduce factor prices (here wages for automation and the rental rate on capital for new tasks).
- This is related to Acemoglu and Autor (2011): technologies change the range of tasks performed by factors, creating “strong price effects”.
- Note also that when \( \tilde{I} < I \), the elasticity of substitution between capital and labor is \( \sigma_{MR} \) rather than \( \sigma_{SR} \) because of the endogenous changes in the set of tasks produced by capital (in response to changes in factor prices).
Special Cases

- Two special cases further highlight the workings of the model: $\eta \rightarrow 0$ (so intermediates determine the equilibrium allocation of tasks to factors, but do not get revenue) or $\zeta \rightarrow 1$ (where their revenues become a constant fraction of total revenue).

- In this case,

$$
\ln \omega = \left( \frac{1}{\hat{\sigma}} - 1 \right) \ln K + \frac{1}{\hat{\sigma}} \ln \left( \frac{\int_{I^*}^{N} \gamma(i)^{\hat{\sigma}-1} di}{I^* - N + 1} \right), \text{ and}
$$

$$
Y = \left[ \left( I^* - N + 1 \right)^{\frac{1}{\hat{\sigma}}} K^{\frac{1}{\hat{\sigma}}} + \left( \int_{I^*}^{N} \gamma(i)^{\hat{\sigma}-1} di \right)^{\frac{1}{\hat{\sigma}}} \right]^{\frac{1}{\hat{\sigma}-1}},
$$

where $\hat{\sigma} \equiv \eta + (1 - \eta)\sigma$ (and thus when $\eta \rightarrow 0$, $\hat{\sigma} = \sigma$), highlighting the role of the two different types of technologies in changing the role of the two factors in the (derived) aggregate production function.

We now move to a dynamic model with capital accumulation and endogenous technological change.

A representative household economy with preferences over consumption

\[ \int_0^\infty e^{-\rho t} \frac{C(t)^{1-\theta} - 1}{1 - \theta} dt. \]

and the resource constraint:

\[ \dot{K}(t) = Y(t) - C(t) - \delta K(t) - \psi \mu \int_{N-1}^N q(i, t) di. \]

\[ r(t) \] is the rental rate of capital and depreciation is \( \delta. \)
The Structure of Balanced Growth Path

- We assume the specific form for the comparative advantage schedule:
  \[ \gamma(i) = e^{Ai}, \text{ with } A > 0. \]

- This implies that labor is more productive in new more complex tasks and will build growth through quality improvements.

- We start by assuming exogenous technological change, and define
  \[ n(t) \equiv N(t) - I(t) \]
Assume \( I^* = I \) (as we will guarantee later).

Normalize the variables \( y(t) \equiv Y(t)/\gamma(I(t)) \), \( k(t) \equiv K(t)/\gamma(I(t)) \), \( c(t) \equiv C(t)/\gamma(I(t)) \), and \( w(t) \equiv W(t)/\gamma(I(t)) \).

The market clearing conditions become:

\[
y(t)(1 - n(t))c^u(r(t))^{\zeta - \sigma} r(t)^{-\zeta} = k(t),
\]

and

\[
y(t) \int_0^{n(t)} \gamma(i)^{\zeta - 1} c^u \left( \frac{w(t)}{\gamma(i)} \right)^{\zeta - \sigma} w^{-\zeta} di = L^s \left( \frac{w(t)}{r(t)k(t)} \right).
\]

Additionally, the ideal price index condition becomes

\[
(1 - n(t))c^u(r(t))^{1 - \sigma} di + \int_0^{n(t)} c^u \left( \frac{w(t)}{\gamma(i)} \right)^{1 - \sigma} di = 1.
\]

These uniquely determine the rate of return on capital, \( r(t) = r^E(n(t), k(t)) \), wages \( w^E(n(t), k(t)) \), and net output, \( f^E(n(t), k(t)) \).
The Structure of Balanced Growth Path (cont)

- Define a BGP as an equilibrium in which $W$, $K$ and $Y$ grow at a constant rate, $g$, and the interest rate, $r$, is constant.

- Thus, in a BGP the normalized variables converge to fixed values, and necessarily $\dot{I} = \dot{N} = \Delta$, so that $n(t)$ is constant.

- Their behavior outside the steady state is determined by the Euler equation

\[
\frac{c'(t)}{c(t)} = \frac{1}{\theta} (r^E(n(t), k(t)) - \delta - \rho) - A\Delta,
\]

and resource constraint

\[
\dot{k}(t) = f^E(k(t), n(t)) - c(t) - (\delta + A\Delta)k(t).
\]
Dynamic Equilibrium: Summary

Proposition (Dynamic equilibrium with exogenous technological change)

Suppose technology evolves exogenously, $\rho > \bar{\rho}$ and $\lim n(t) > \bar{n}$ for all $t \geq T$.

1. Asymptotically, $I^* = I$ and all automated tasks produce with capital.

2. A balanced growth path exists if and only if asymptotically $\dot{N} = \dot{I} = \Delta$. In this balanced growth path $I^* = I$. $Y$, $C$, $K$ and $w$ grow at a constant rate $A\Delta$ and $r$ is constant.

3. Given such a path for technology, the dynamic equilibrium is unique starting from any initial condition and converges to the balanced growth path.
Dynamic Equilibrium: Diagrammatic Representation

Figure: BGP and dynamics for our model with exogenous technological change and \( n(t) \to n \).
The Productivity Effect

- Consider the balanced growth path characterized above with $N(t) - I(t) = n$ and $g = A\Delta$. Crucially, in the long run $r = \rho + \delta + \theta g$.
- The long-run effect of technology on wages can now be computed from the ideal price index condition:

$$
(I - N - 1)c(u)(\rho + \delta + \theta g)^{1-\sigma} + \int_I^N c(u) \left( \frac{W}{\gamma(i)} \right)^{1-\sigma} = 1. \tag{8}
$$

This in particular implies:

$$
\frac{dW}{dl} \propto \frac{1}{\sigma - 1} \left[ c(u)(r)^{1-\sigma} - c(u) \left( \frac{W}{\gamma(l)} \right)^{1-\sigma} \right] \geq 0.
$$

- Thus, several of the intuitive results from the static model continue to apply, but because of the productivity effect, automation also increases the wage level in the long run.
The Productivity Effect and Wages

**Figure:** Evolution of wages following a one-time temporary increase in $\dot{I}$
We now endogenize technology by assuming that it can be developed by firms using scientists, which are in inelastic supply, $S$.

$S_I(t) \geq 0$ of these scientists are hired by monopolists at a competitive wage $w^S$ for automation, and $S_N(t) \geq 0$ of them are hired for creating new tasks. The market clearing condition for scientists is

$$S_I(t) + S_N(t) \leq S.$$ 

Advances in automation and creation of new tasks follow the next two differential equations

$$\dot{I}(t) = \kappa_I S_I(t),$$  \hspace{1cm} (9)

and

$$\dot{N}(t) = \kappa_N S_N(t),$$ \hspace{1cm} (10)

where $\kappa_I$ and $\kappa_N$ are positive constants.
The flow profits from automation, which naturally replaces a task previously performed by labor (i.e., $i > I(t)$), can be written as

$$\pi_I(t, i) = (1 - \mu) \left( \frac{\eta}{1 - \eta} \right)^{\zeta} \psi^{1-\zeta} Y(t) c^u (r(t))^{\zeta-\sigma}.$$ 

Flow profits of producing such task with an intermediate technology that only allows the use of labor, is given by

$$\pi_N(t, i) = (1 - \mu) \left( \frac{\eta}{1 - \eta} \right)^{\zeta} \psi^{1-\zeta} c^u \left( \frac{W(t)}{\gamma(i)} \right)^{\zeta-\sigma}.$$
We assume a patent structure in which new entrants must compensate replaced firms by making a take-it-or-leave it offer.

With this patent structure, new firms will compensate existing patent holders by their full continuation value of production.

Therefore, values from automation and new labor-intensive tasks depend on differences in costs:

$$V_I(t) \propto \int_t^\infty e^{-\int_t^\tau r(s) \, ds} Y(\tau) \left( c^u (r(\tau))^{\zeta-\sigma} - c^u \left( \frac{W(\tau)}{\gamma(I(t))} \right)^{\zeta-\sigma} \right) d\tau, \quad (11)$$

and

$$V_N(t) \propto \int_t^\infty e^{-\int_t^\tau r(s) \, ds} Y(\tau) \left( c^u \left( \frac{W(\tau)}{\gamma(N(t))} \right)^{\zeta-\sigma} - c^u (r(\tau))^{\zeta-\sigma} \right) d\tau. \quad (12)$$

Observe that these values are positive only when $\sigma > \zeta$. 
A dynamic equilibrium with endogenous technology is determined by:

- The evolution of the state variables is given by
  \[
  \dot{k}(t) = f^E(k(t), n(t)) - c(t) - (\delta + A\kappa_I S_I(t))k(t) \\
  \dot{n}(t) = \kappa_N(S - S_I(t)) - \kappa_I S_I(t).
  \]

- Consumption satisfies the Euler equation
  \[
  \dot{c}(t) = c(t) \left( \frac{1}{\theta}(r^E(k(t), n(t)) - \delta - \rho) - A\kappa_I S_I(t) \right).
  \]

- The allocation of scientists satisfies:
  \[
  S_I(t) = \begin{cases} 
  0 & \text{if } \kappa_I V_I(t) < \kappa_N V_N(t) \\
  \in [0, S] & \text{if } \kappa_I V_I(t) = \kappa_N V_N(t) \\
  S & \text{if } \kappa_I V_I(t) > \kappa_N V_N(t)
  \end{cases}
  ,
  \]
  with $V_N(t)$ and $V_I(t)$ given by equations (11) and (12).

- A transversality condition for the household holds.
Proposition (Equilibrium with endogenous technological change)

Suppose that $\sigma > \zeta$, $\rho > \bar{\rho}$ and $S < \bar{S}$ (where $\bar{S}$ is a suitably defined threshold). Then:

1. There exists $\kappa$ such that for $\kappa I_N > \kappa$ there is a unique balanced growth path.
2. Along this path we have $I^*(t) = I(t)$ and $N(t) - I(t) = n^D$, with $n^D$ determined endogenously from the condition $\kappa N V_N = \kappa I V_I$. In this balanced growth path, $Y$, $C$, $K$ and $W$ grow at the constant rate $g = A \frac{\kappa I N}{\kappa I + \kappa N} S$, and $r$, the labor share and employment are constant.
3. The dynamic equilibrium is unique in the neighborhood of the balanced growth path and is locally (saddle-path) stable. Moreover, when $\theta \to 0$, the dynamic equilibrium is globally stable.
Determination of the Balanced Growth Path

Figure: Determination of \( n^D \) in steady state.
Consider an increase in $I$ away from the balance growth path. This reduces the labor share and total employment.

But it also reduces the wage per effective unit of labor $W/\gamma(I)$ relative to interest rates.

Profit-making incentives create forces for **self-correction**, i.e., for the economy to revert back to the same balanced growth path, employment and factor shares.

The role of $\sigma > \zeta$ is important: an increase in $I$ reduces $W/\gamma(I)$ and this *increases* $V_N(t)$ relative to $V_I(t)$, providing incentives for monopolists to introduce new more complex (more labor-intensive) tasks, instead of automating tasks in which the production cost with labor has fallen.

But this effect needs to be stronger than the productivity effect. Our assumptions ensured that it is.
Reducing Automation May Improve Welfare

- Is the composition of innovation socially optimal?
- In general no, and there is too much automation and too little creation of new tasks because of labor’s quasi rents.

**Proposition (Excessive automation)**

Suppose that $\rho > \rho$ and $S < \bar{S}$ as in Proposition 5, and that $\sigma > \zeta \to 1$. Moreover, suppose intermediate goods are subsidized and can be purchased at their marginal cost (or equivalently $\mu \to 1$).

Consider the decentralized equilibrium path starting from some initial level of capital, $K(0)$, and endogenous technologies, $N(t) - I(t) = n^D(t)$.

There exists a feasible allocation satisfying $n^P(t) \geq n^D(t)$ with $\lim_{t \to \infty} n^P(t) > n^D$ that achieves strictly greater welfare than the decentralized equilibrium.
Extensions I: Automation and Inequality

We include two types of labor, high and low skill, and assume that new tasks are at first produced by skilled labor, and then can be standardized (in a manner similar to Acemoglu, Garcia and Zilibotti, 2012) with unskilled labor, before being further standardized to be produced by capital.

Suppose that for high- and low-skill workers comparative advantage is

\[ \gamma_H(i) = e^{A_H i}, \text{ and} \]
\[ \gamma_L(i, t) = e^{A_L i + (A_H - A_L) \Delta(t - t_0(i))}, \]

where \( A_L < A_H \) and \( t \) is calendar time and \( t_0(i) \) the date at which task \( i \) was introduced.

This implies that there exists a threshold task \( M \) such that high-skill labor performs tasks in \( (M, N] \), low-skill labor performs tasks in \( (I, M] \), and tasks in \( [N - 1, M] \) are performed by capital.
Automation and Inequality: Main Result

Proposition (Automation, new tasks and inequality)

Suppose technology evolves exogenously:

1. Then a balanced growth path exists if and only if asymptotically $\dot{N} = \dot{I} = \Delta$. In this balanced growth path $Y, C, K$ and $w_H, w_L$ grow at a constant rate $A_H \Delta$ and $r$ is constant. Moreover, the wage ratio between high-skilled and low-skilled workers $(w_H/w_L)$ is constant but depends on $n = N - I$.

2. Given such a path of technological change, the dynamic equilibrium is unique starting from any initial condition and converges to the balanced growth path.

3. The immediate effect of increases in both $I$ and $N$ is to increase $W_H/W_L$. But the medium-run impact of an increase in $N$ is to reduce inequality.
Another extension is to modify the assumption we have made on the structural intellectual property rights, reverting to the more standard assumption that new technologies creatively destroy the rents/profits of existing technologies.

The computation of $V_N(t)$ and $V_I(t)$ is more involved, but we still obtain a BGP (and also stability under additional conditions).

Yet, stability requires more stringent assumptions.

This occurs because firms do not take into account the cost of production with other inputs when deciding whether to automate or create new tasks.
Our main contribution is to develop a systematic framework in which the force of capital replacing previously labor-intensive tasks is partially or fully countered by the creation of new labor-intensive tasks.

The framework lends itself to determine the conditions under which sustained technological progress will be consistent with balanced growth.

The framework also shows how different types of technological changes impact factor shares, and in an extension including search and matching, unemployment.

It also highlights the forces that will self-correct bouts of technological change that greatly distort the factor distribution of income.