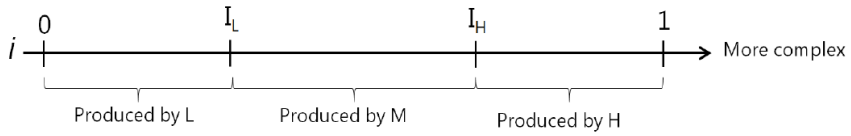
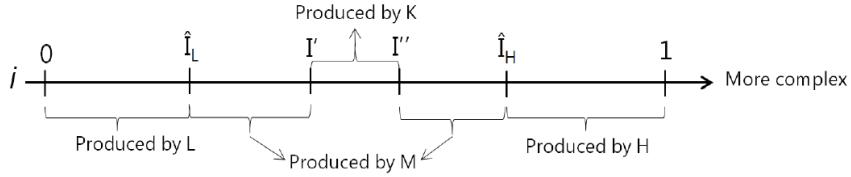
Part 1: Essay questions

Question 1a. The medium skilled workers made redundant by automation (capital) will be employed in jobs previously held by workers with either higher or lower skill levels, as illustrated in the following diagram:

Before replacement by capital:



After replacement by capital:



The stock of suddenly redundant medium skill workers reduces medium skill wages. Firms therefore substitute high and low skill labor for medium skill labor in occupations where medium skill workers are now cheaper to employ. That medium skilled workers become employed in new occupations does not compensate for the initial wage loss, as their comparative advantage in the new occupations is smaller than in the occupations taken over by machines.

Question 1b: Wikipedia is free and has negligible costs, so it does not contribute to GDP directly. Wikipedia has replaced physical encyclopedias, which had a positive price tag. The weight of encyclopedias in GDP has therefore fallen. Consumers are likely to spent their savings on encyclopedias elsewhere in the economy, so measured GDP will not fall. It will not rise either, since the consumer surplus from a free encyclopedia is not counted in GDP (Wikipedia is produced by volunteers, so it falls within home production). Real consumption is, on the other hand higher because of Wikipedia.

Spotify has a fixed cost per month, and the number of Spotify subscribers are therefore part of GDP. However, since marginal use is free, consumers will most likely listen to a much larger variety of artists on Spotify than they would if they had to buy CDs. Since this increased music consumption is free, it is not fully captured by measured GDP allthough it has reduced the cost of music greatly. Both true real GDP and real consumption should increase.

AirBnB customers pay by the night as they do at normal hotels, so AirBnB do not lead to the same kind of bias to measured GDP as free internet services

do. However, AirBnB allow households to use their home as a productive asset, and diminish the need for investment in the hotel business. This will tend to reduce the ratio of investment to consumption in GDP, since home ownership (or rental) is included in the consumption component of GDP. The Bean Report on the reading also mention that because AirBnB is a new product, the lower prices for AirBnB accomodation is not yeat taken into account when accomodation services are deflated in the national accounts.

Question 1c: In the Hsieh and Moretti model, workers split their income between consumption, which generates utility, and housing. If house prices vary across cities, then workers in expensive cities has to be compensated by higher wages, or they will choose to move elsewhere. This creates a link between house prices and marginal products of labor. Municipal-level housing policies can therefore be a source of misallocation in the national labor market if they distort house prices. Housing in high-productivity regions is, for instance, often expensive because local politicians restrict supply. Students can mention San Francisco, San Jose and New York as examples. Supply restrictions (NIMBY-ism) in such places may be popular among local voters, but costly for outsiders for whom it may be too expensive to move to the more productive region. Because decisions about local housing supply has implications for nation-wide welfare, they should be made nationally rather than by the municipality.

Question 1d: (i) Internal learning refers to firm-specific learning, whereas external learning refers to a situation where productive knowledge obtained via learning-by-doing influences the productivity of other firms in the economy. The distrinction is key. Internal learning refers to the setting where learning within a firm increases the productivity of said firm; external learning arises when learning within a firm influences the productivity of other firms.

External learning is required for endogenous growth in a competitiv setting. With internal learning one would expect the firm (sooner or later) to internalize the learning gains, which potentially leads to increasing return. The latter is irreconsilable with fully competitive markets. External learning gains are less likely to eb internalized, however. Even though external learning thus allows for increasing returns to scale *in the aggregate*, it can be reconsiable with competitive markets.

(ii) Knowledge spillovers in the conduit through which external learning arises. That is, it captures the process whereby learning is transmitted from one (say worker) to another.

The classic example is the liberty ship yeard "miracle". It is analyzed in Thornton and Thompson (2001), who document not only the existence of internal learning (gains within same ship-type and shi-pyard) but also across yards and ship types. Quantitatively, however, the gains appear to be too modest to be able to support endogenous growth. TT also explains why knowledge spillovers arises in the war setting. Deliberate attempts (via e.g. coordination meetings across yards) to share knowledge, ensuring new ideas were transmitted to other yards.

Question 1.e: No not nessesarily. Integration of the labor markets will exert a postive influence on growth in the AH model. A greater labor force leads to a lower wage, which lowers the cost of R&D leading to more R&D workers in equilibrium. As a result the expected growth rate rises since each researcher is assumed to innovate with a fixed flow probability. More competition, however, by lowering profits diminishes the incentive to innovate and thus the demand for R&D. As a result, the net impact from (this kind of) integrations has an ambigious effect on growth.

Question 1.f: No, if an expansion of the capital stock (or output) leads the public good to be *congested*. In such a setting higher output (more capital) is asssociated with a *negative* externality, which a distortionay tax (say on output) helps correct.

Part 2: Beyond GDP

Question 2a: λ_i is a consumption-equivalent measure of relative welfare. It measures by how much a person living in the United States should be compensated for living in country i.

Question 2b: Plug $u(C,l)$ into U_i and set $\beta = 1$ and growth equal to zero:

$$U_i = E\sum_{a=1}^{100}\left[\bar{u} + \log C_i + v\left(l_i\right)\right] S_i\left(a\right)$$

Use the property of the lognormal distribution that $E\left[\log x\right] = \log x - \frac{\sigma^2}{2}$:

$$\begin{aligned} U_i &= \left[\bar{u} + \log c_i - \frac{\sigma_i^2}{2} + v\left(l_i\right)\right] E\sum_{a=1}^{100} S_i\left(a\right) \\ &= \left[\bar{u} + \log c_i - \frac{\sigma_i^2}{2} + v\left(l_i\right)\right] e_i \end{aligned}$$

Question 2c:

$$\begin{aligned} U_{us}\left(\lambda_i\right) &= U_i\left(1\right) \\ &\Leftrightarrow \left[\bar{u} + \log\left(\lambda_i c_{us}\right) - \frac{\sigma_{us}^2}{2} + v\left(l_{us}\right)\right] e_{us} = \left[\bar{u} + \log\left(1 \cdot c_i\right) - \frac{\sigma_i^2}{2} + v\left(l_i\right)\right] e_i \\ &\Leftrightarrow e_{us}\log\lambda_i = \left[\bar{u} + \log\left(c_i\right) - \frac{\sigma_i^2}{2} + v\left(l_i\right)\right] e_i - \left[\bar{u} + \log\left(c_{us}\right) - \frac{\sigma_{us}^2}{2} + v\left(l_{us}\right)\right] e_{us} \end{aligned}$$

Add and subtract $\left[\bar{u} + \log\left(c_i\right) - \frac{\sigma_i^2}{2} + v\left(l_i\right)\right] e_{us}$ on the right hand side:

$$
\begin{aligned}
e_{us}\log\lambda_i &= \left[\bar{u}+\log\left(c_i\right)-\frac{\sigma_i^2}{2}+v\left(l_i\right)\right]\left(e_i-e_{us}\right) \\
&\quad -\left[\bar{u}+\log\left(c_{us}\right)-\frac{\sigma_{us}^2}{2}+v\left(l_{us}\right)\right]e_{us}+\left[\bar{u}+\log\left(c_i\right)-\frac{\sigma_i^2}{2}+v\left(l_i\right)\right]e_{us}
\end{aligned}
$$

Divide through by e_{us} and collect terms to arrive at:

$$
\begin{array}{lll}
\log\lambda_i = & \frac{e_i-e_{US}}{e_{US}}\left(\bar{u}+\log c_i+v\left(\ell_i\right)-\frac{1}{2}\sigma_i\right) & (Life\ expectancy) \\
& +\log c_i-\log c_{US} & (Consumption) \\
& +v\left(\ell_i\right)-v\left(\ell_{US}\right) & (Leisure) \\
& -\frac{1}{2}\left(\sigma_i-\sigma_{US}\right) & (Inequality)
\end{array}
$$

Life expectancy, consumption, leisure and inequality are readily available in macro data for a large set of countries. Both $\bar{u}$ and v can be calibrated. With these data, λ_i can be computed for any country i to obtain a measure of consumption equivalent welfare.

Question 2d: GDP/capita does not enter λ_i directly, but has a high and positive correlation with both consumption and life expectancy. Leisure also tends to increase with income levels, while the relationship between GDP/capita and inequality is less clear. Combined, these correlations suggest that GDP/capita and consumption-equivalent welfare should be highly correlated. Indeed, Jones and Klenow (2016) find the correlation to be 0.96 in a cross section of 152 countries. Despite the high correlation, there are still significant variation in welfare across countries with similar levels of GDP/capita.

Whereas GDP/capita rankings closely resemple rankings of countries according to welfare levels, global inequality is significantly higher when measured in welfare terms. The reason is that poor countries, because they are poor, also tend to have lower life expectancy than rich countries. People in poor countries are in that sense hit twice by low GDP/capita levels.

Part 3: R&D driven growth

Question 3.a. Combining equation (1) and (2) and using the balanced growth assumption we get

$$
\gamma = \frac{1}{\theta}\left(r-\rho\right)
$$

$$
\gamma = \bar{\delta}\left(H-\frac{1}{\bar{\delta}}\frac{\alpha}{\left(\alpha+\beta\right)\left(1-\alpha-\beta\right)}r\right)
$$

Accordingly, the top equation has a positive slope reflecting that as the real rate of interest up individuals prefer to allow consumption to grow over time. The bottom equation has a negative slope. It reflects that as the interest rate

increases the marginal costs of producing intermediate goods goes up, lowering profits and thus the demand for new ideas.

(ii) If H increases the growth rate and the real rate of interest increases: The lower equation shifts out. The reason is that a bigger supply of skilled labor reduces the skilled wage, which allows for more skilled labor in the final goods sector and the R&D sector (due to free mobility). In addition, more skilled labor in the final goods sector expands the demand for intermediate goods which raises profits and thus increases the demand for R&D. Greater demand for physical capital (due to the acceleration in R&D and growth) leads to a higher equilibrium real rate of interest in order to persuade the consumers to defer consumption. This prediction does not appear to be supported: Over the last half century R&D labor has increased but growth has not (nor has the real rate of return increased).

Question 3.b: Combining (4) and (5) we get

$$\frac{\dot{A}(t)}{A(t)} = \frac{\bar{\delta} A(t)^{\phi} H_A(t)}{A(t)}, \tag{1}$$

Under the assumption of constant allocation of labor

$$\frac{\dot{H}_A}{H_A} = \frac{\dot{H}}{H} = n$$

and balanced growth also means the growth rate of A is constant. This requires

$$(\phi - 1)\frac{\dot{A}}{A} + n = 0$$

or

$$\gamma_A = \frac{n}{1-\phi} \equiv \gamma.$$

Question 3.c: The assumption implies that research productivity is declining as the stock of knowledge increases. Define R&D TFP as

$$TFP_{R\&D} \equiv \frac{\gamma_A}{H_A} = \frac{\delta(t)}{A} = \bar{\delta} A^{\phi - 1},$$

i.e., as the residual when we correct output (γ_A) for rival inputs (R&D labor, H_A). That is, as more knowledge is required the next step becomes progressively more difficult: "low hanging fruits" are depleted. This is often referred to as the "fishing-out" effect.

This scenario is supported by the work of Bloom et al (2018) who document that whereas productivity growth has been fairly constant over the last several decades R&D input has grown considerably implying declining $TFP_{R\&D}$. Hence, to sustain growth it is imperative that R&D input rises. If that ceases, so does exponential growth.

Question 3.d: As noted the model is only modified in the stated direction (i.e., wrt R&D production). Hence, the equation

$$\gamma = \bar{\delta}\left(H - \frac{1}{\bar{\delta}}\frac{\alpha}{(\alpha+\beta)(1-\alpha-\beta)}r\right)$$

is simply replaced by

$$\gamma = \frac{n}{1-\phi},$$

which is independent of r. The intersection between the lower equation (indepedent of r) and $\gamma = \frac{1}{\theta}(r-\rho)$ thus determines the real rate of interest (and the new equation $\frac{n}{1-\phi} = \delta H_A$ determines R&D input after which labor in the final good sector is given by $H - H_A$).Hence, if n declines the real rate of return declines in the economy alongside the overall growth rate in GDP. With slower growth in ideas the demand for capital declines, which induces the equilibrium interest rate to decline.