Agricultural Employment and the Economic Transition from Malthus to Solow

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Abstract

We develop a simple model where the final output is produced using two technologies—one with diminishing returns and another with constant returns—and labor as the sole input. We show that the rate of decline in the share of agricultural employment is a sufficient statistic for the onset of economic transition from stagnation to sustained growth. Our quantitative results are consistent with the implications for the evolution of per capita income for economies in various stages of development and structural transformation.

JEL codes: O10, O13, O40.

Federal Reserve Bank of St. Louis *Review*, First Quarter 2026, Vol. 108, No. 1, pp. 1-8.
https://doi.org/10.20955/r.2026.01

1. INTRODUCTION

The world has transitioned from stagnation—roughly constant per capita income prior to the 19th century—to sustained growth in per capita income after the Industrial Revolution (see Figure 5.3 in Lucas, 2002). This phenomenon, commonly referred to as a transition from Malthus to Solow, has been the subject of several papers, including models of economic and fertility transitions (Becker, Murphy, and Tamura, 1990; Galor and Weil, 2000), a model of transition from home production to market production (Goodfriend and McDermott, 1995), a model where the transition is triggered by a threshold level of physical capital and total factor productivity (TFP) (Hansen and Prescott, 2002), and a model in which the transition results from human capital accumulation and reductions in trade costs (Tamura, 2002). In quantitative implementations of these models, the date of economic transition is typically a calibration target. The approach is to calibrate the model to deliver the onset of economic transition observed in the real gross domestic product (GDP) of developed economies that have historical data, e.g., the United Kingdom.

In this article, we show that data on recent agricultural employment is sufficient to pin down the date of economic transition. Our approach has two advantages. First, since we do not use GDP data, one can test whether the onset of transition delivered by agricultural employment matches the onset implied by GDP. Second, our approach is useful in the context of economies that do not have historical data and are usually not examined in the transition literature.

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Michael Owyang and Juan Sánchez are editors in chief of the *Review*. They are supported by Research Division economists and research fellows, who provide input and referee reports on the submitted articles.

Our model is a simpler version of those in Hansen and Prescott (2002) and Tamura (2002). A single final good can be produced using a diminishing-returns technology, labeled as Malthus, and/or a constant returns technology, labeled as Solow. Labor is the only input to both Malthus and Solow technologies. TFP in the two technologies and total employment are exogenous and grow at possibly different rates.

Initially, all of the workers are employed in the Malthus technology. The onset of transition is when some of the workers are employed in the Solow technology, i.e., when employment in the Malthus technology starts declining. In our model, the labor allocation to the two technologies is a solution to a static problem, and the dynamics of the allocation are entirely due to the exogenous evolution of the total employment and the two TFPs. We show that the share of employment in the Malthus technology declines at a constant rate during the transition.

For our quantitative exercises, we map the Malthus technology to agriculture, so the share of agricultural employment declines at a constant rate during the transition. Thus, we can use a few years of recent data on the share to infer the rate of decline. We can then project backward and pin down the onset of transition; we do not need to know the structural parameters or the growth rates of TFPs or total employment. In other words, the recent share of agricultural employment is a sufficient statistic to compute the onset of economic transition.

Quantitatively, we estimate the rate of decline in the share of agricultural employment for four countries—Sweden, Portugal, Brazil, and India—using data from 1991 to 2022 and infer the onset of economic transition for each. Our estimates are 1851 for Sweden, 1925 for Portugal, 1930 for Brazil, and 1964 for India. We then validate these estimates with GDP data: The trend in per capita GDP before the onset is lower than the trend after the onset.

There is no a priori reason that agricultural employment over a recent few years would pin down GDP dynamics over many years and for countries that differ in many aspects. In the case of Sweden, we validate our estimate of the onset using more than four centuries of GDP, and for India, we use more than a century of GDP data. Sweden was characterized by large structural changes, and India is a poorer country relative to Sweden and in a different phase of structural transformation.

Two remarks are in order here. First, our model does not rely on preferences. It is a classical theory of the onset of economic transition and the ensuing dynamics. Second, the model lacks endogenous fertility, multiple goods, distortions, trade, structural transformation, subsistence agriculture, and so on, none of which seems to be necessary to pin down the onset of economic transition. This poses a challenge to other models with more elaborate features, as they must confront the quantitative importance of recent agriculture. How is it that a few recent observations on agricultural employment are sufficient to pin down the onset of GDP transition for economies in various stages of development and structural transformation?

2. MODEL

Our model is the same as in Ravikumar and Vandenbroucke (2025), which is a simplified version of the models in Hansen and Prescott (2002) and Tamura (2002). Relative to Hansen and Prescott (2002), the model abstracts from capital and population that are functions of dynamic consumption choices, and unlike Tamura (2002), the model abstracts from endogenous fertility and human capital accumulation. We describe the model here for the sake of completeness.

The economy has a single consumption good. Two technologies, labeled Malthus (M) and Solow (S), can be used to produce this good. The Malthus technology uses labor and a fixed amount of land (normalized to 1), while the Solow technology uses only labor. The former exhibits diminishing returns to labor, and the latter exhibits constant returns. Outputs at time t from the two technologies are denoted by Y_t^M and Y_t^S, respectively:

$$Y_t^M = \left(Z_t^M N_t^M\right)^{1-\alpha}, \quad \alpha \in (0,1), \quad \text{and} \quad Y_t^S = Z_t^S N_t^S,$$

where Z_t^M and Z_t^S are exogenous TFPs and N_t^M and N_t^S are employment in technologies M and S at t, respectively. Total GDP is $Y_t = Y_t^M + Y_t^S$.

Total labor endowment at t is N_t. There are no impediments to labor mobility between the two technologies, so $N_t^M + N_t^S \leq N_t$ at every point in time.

Time is continuous and the time horizon is infinite. In what follows, we use lowercase letters to denote a variable per capita: $x_t \equiv X_t/N_t$. (We use the terms population, total labor, and total employment interchangeably.)

We assume that Z_t^S, Z_t^M, and N_t grow at constant but potentially different rates γ_Z^S, γ_Z^M, and γ_N, respectively:

$$Z_t^S = Z_0^S \exp\left(t\gamma_Z^S\right),\ Z_t^M = Z_0^M \exp\left(t\gamma_Z^M\right),\ \text{and}\ N_t = N_0 \exp\left(t\gamma_N\right),$$

where Z_0^S, Z_0^M, and N_0 are initial conditions.

The optimal allocation of labor maximizes the economy's output of the single good and satisfies the inequality:

$$Z_t^S \leq (1-\alpha)\left(Z_t^M\right)^{1-\alpha}\left(N_t^M\right)^{-\alpha}. \tag{1}$$

The left-hand side is the marginal product of labor in the Solow technology, and the right-hand side is the marginal product of labor in the Malthus technology. When Z_t^S is sufficiently low, the marginal product of labor in the Malthus technology exceeds that in the Solow technology even if all workers are allocated to the Malthus technology. Thus, the optimal allocation must allow for the possibility that there might be periods where only one technology is used to produce the good. When Z_t^S is sufficiently high, the optimal allocation is an interior solution and (1) holds with equality.

Assumption 1. *Initial conditions are such that*

$$Z_0^S < (1-\alpha)\left(Z_0^M\right)^{1-\alpha}\left(N_0\right)^{-\alpha}.$$

In this case, all workers are allocated to the Malthus technology at date 0; i.e., $N_0^M = N_0$. If $Z_t^S < (1-\alpha)\left(Z_t^M\right)^{1-\alpha}\left(N_t\right)^{-\alpha}$ at date t, then all workers continue to be allocated to the Malthus technology at t.

When will some of the workers be allocated to the Solow technology? For this to occur, the two sides of (1) must be equal at some future date.

Assumption 2. *The growth rates of labor and the two TFPs are such that*

$$\gamma_Z^S > (1-\alpha)\gamma_Z^M - \alpha\gamma_N.$$

For an interior solution to emerge in the future, the TFP growth rate in the Solow technology must be sufficiently large. For the rest of the article, we maintain assumptions 1 and 2.

Using (1), the date at which the economy starts operating the Solow technology, t^*, is determined by

$$Z_0^S e^{t^*\gamma_Z^S} = (1-\alpha)\left(Z_0^M e^{t^*\gamma_Z^M}\right)^{1-\alpha}\left(N_0 e^{t^*\gamma_N}\right)^{-\alpha}.$$

That is, the onset of transition from the Malthus technology to the Solow technology is given by

$$t^* = \frac{\ln\left[(1-\alpha)\left(Z_0^S\right)^{-1}\left(Z_0^M\right)^{1-\alpha}\left(N_0\right)^{-\alpha}\right]}{\gamma_Z^S - (1-\alpha)\gamma_Z^M + \alpha\gamma_N}. \tag{2}$$

A few remarks about the model are in order here.

Remark 1. *The only choice variable in the model is the employment in the Malthus technology. The optimal choice is a solution to a static problem. The two TFPs and total employment are exogenous and govern the dynamics of employment in the Malthus technology.*

Remark 2. *Under assumption 1, the economy will always start with only the Malthus technology producing the good.*

Remark 3. *Assumption 2 ensures that the economy will not be stuck in a Malthusian trap.*

It is convenient to analyze the economy in two parts: before t^* and during the transition after t^*.

Before the transition. All workers are employed in the Malthus technology. Consequently, total output in the economy is produced by that technology.

$$\begin{aligned}
\text{Share of employment in } M &: \quad n_t^M = 1,\\
\text{GDP per capita} &: \quad y_t = y_t^M = \left(Z_t^M\right)^{1-\alpha}\left(N_t\right)^{-\alpha},\\
\text{Per capita GDP growth} &: \quad \frac{d\ln(y_t)}{dt} = \gamma_y^M = (1-\alpha)\gamma_Z^M - \alpha\gamma_N.
\end{aligned}$$

Before the transition, the growth rate of the *employment share* is 0, and per capita GDP growth rate is constant. Cross-country differences in structural parameters, such as α, and differences in the dynamics of TFPs and total employment imply differences in per capita GDP growth rate before the transition.

During the transition. When both technologies operate, (1) holds with equality and employment in the Malthus technology is

$$N_t^M = (1-\alpha)^{1/\alpha} \frac{1}{Z_t^S} \left(\frac{Z_t^M}{Z_t^S} \right)^{(1-\alpha)/\alpha}.$$

Hence, in the Malthus technology, the employment share and its growth rate are

$$n_t^M = (1-\alpha)^{1/\alpha} \frac{1}{Z_t^S N_t} \left(\frac{Z_t^M}{Z_t^S} \right)^{(1-\alpha)/\alpha}, \tag{3}$$

$$\frac{d\ln(n_t^M)}{dt} \equiv \gamma_n^M = \frac{1-\alpha}{\alpha}\gamma_Z^M - \frac{1}{\alpha}\gamma_Z^S - \gamma_N. \tag{4}$$

Using the solution for N_t^M during the transition ($t \geq t^*$), the output of the Malthus technology when both technologies operate is

$$Y_t^M = \left(Z_t^M\right)^{1-\alpha} \left[(1-\alpha) \frac{\left(Z_t^M\right)^{1-\alpha}}{Z_t^S} \right]^{(1-\alpha)/\alpha} = (1-\alpha)^{(1-\alpha)/\alpha} \left(\frac{Z_t^M}{Z_t^S} \right)^{(1-\alpha)/\alpha},$$

implying that output per capita is

$$y_t^M = \frac{1}{1-\alpha} Z_t^S n_t^M.$$

For the Solow technology, when both technologies operate, output per capita is

$$y_t^S = Z_t^S(1-n_t^M) = Z_t^S - (1-\alpha)y_t^M.$$

The economy's per capita GDP is $y_t = y_t^S + y_t^M$. Therefore,

$$y_t = Z_t^S + \frac{\alpha}{1-\alpha} Z_t^S n_t^M. \tag{5}$$

A few remarks on the dynamics of n^M and y are worth making here.

Remark 4. *Equalizing marginal products of labor in the two technologies yields equation* (3)*. Since* Z^S*,* N*, and* Z^M *grow at constant rates, equation* (3) *implies that the growth rate of* n^M *is constant. From Assumption 2,* $(1-\alpha)\gamma_Z^M - \alpha\gamma_N < \gamma_Z^S$*, so equation* (4) *implies that the employment share in the Malthus technology declines at a constant rate after* t^**.*

Remark 5. *Equation* (5) *implies that the long-run path of per capita GDP is* Z_t^S *and the long-run growth rate is* γ_Z^S*.*

Remark 6. *For the economy to transition from Malthus to Solow, Assumption 2 must be satisfied: The long-run growth rate of per capita GDP must be higher than the pre-transition growth rate* γ_y^M*.*

Remark 7. *The relative deviation of per capita GDP from its long-run path, which we denote by* $\hat{y}_t$*, is then*

$$\hat{y}_t \equiv \frac{y_t - Z_t^S}{Z_t^S} = \frac{\alpha}{1-\alpha} n_t^M, \quad \textit{for} \ \ t \geq t^*.$$

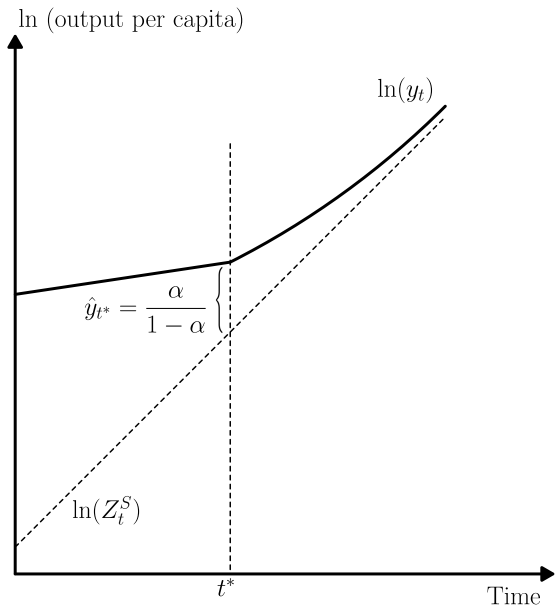
As the share of employment in the Malthus technology declines, $\hat{y}_t$ *approaches zero and the paths of per capita GDP and* Z^S *converge.*

Figure 1 illustrates a path of $\hat{y}_t$. At t^*, $n_M = 1$, so $\hat{y}_{t^*} = \frac{\alpha}{1-\alpha}$. The path of per capita GDP before t^* need not be positively sloped; it could be flat and depends on the values of α, γ_Z^M, and γ_N.

The onset of sustained growth in our model is when the Solow technology starts operating at date t^*. While equation (2) pins down t^*, the expression depends on estimates of initial conditions and growth rates of TFPs and employment. In the following proposition, we show an alternative, practical way to determine t^*.

Proposition. *The share of employment in the Malthus technology is a sufficient statistic to determine the onset of transition* t^**.*

Figure 1
Per Capita Output



NOTE: The figure shows an illustrative path of per capita GDP under the assumption that the exogenous variables grow at constant, but potentially different, rates.

Proof. *Since γ_n^M is constant, $n_t^M = \exp\left((t - t^*)\gamma_n^M\right)$ for $t \geq t^*$, or*

(6) $$t^* = t - \frac{\ln\left(n_t^M\right)}{\gamma_n^M}, \quad \textit{for } t \geq t^*.$$

As noted in Remark 4, the share of employment in the Malthus technology declines at a constant rate during the transition. Thus, if we know the share's current level and rate of decline, then we can project backward and compute when the share would have been 1. That is, we can determine the onset of the transition using just the current information on the share of employment in the Malthus technology, even though the onset could have been several periods earlier.

Equation (6) implies that the reasons why different countries have different n^M or γ_n^M do not matter for estimating the onset of transition from Malthus to Solow. Countries could differ in their structural parameters and in the levels and growth rates of TFPs and total employment. In our model, these differences manifest themselves in different n_t^M and γ_n^M (see equations (3) and (4)).

3. QUANTITATIVE ANALYSIS

Proposition 1 shows that the employment share in the Malthus technology is sufficient to determine t^*. Quantitatively, we map the employment share in the Malthus technology in the model to the share of agricultural employment in the data.[1]

Note that both the level and growth rate of the share of agricultural employment are needed to estimate the onset of transition. Countries with the same share at a point in time could have started their transitions at different times. Since the model implies that the growth rate of this share is constant, a few recent (presumably more reliable) observations are sufficient to determine the onset of transition. Hence, we do not need historical evidence on the share of agricultural employment.

1. With this mapping, one might think that a relative price is involved in the GDP calculation, which is missing in our model. However, we could easily include the relative price of a non-agricultural good and/or inputs other than labor into one of the two exogenous TFPs in our model. For instance, the evolution of Z^S could capture the dynamics of the relative price.

To operationalize equation (6), consider the following specification for country i:

$$\ln(n^M_{t,i}) = \beta_{0,i} + \beta_{1,i}t, \tag{7}$$

which implies $\beta_{1,i} = \gamma^M_{n,i}$. At the onset of transition, $n^M = 1$, so

$$t^*_i = -\frac{\beta_{0,i}}{\beta_{1,i}}. \tag{8}$$

We illustrate our approach by estimating the onset of transition for four economies: Sweden, Portugal, Brazil, and India. They differ in stages of development and structural transformation, as shown in Table 1.

Table 1
Stages of Development of Four Economies in 2016

	Sweden	Portugal	Brazil	India
Per capita GDP relative to the U.S., %	84.3	47.7	26.2	11.5
Share of agricultural employment, %	1.9	5.0	8.7	42.9

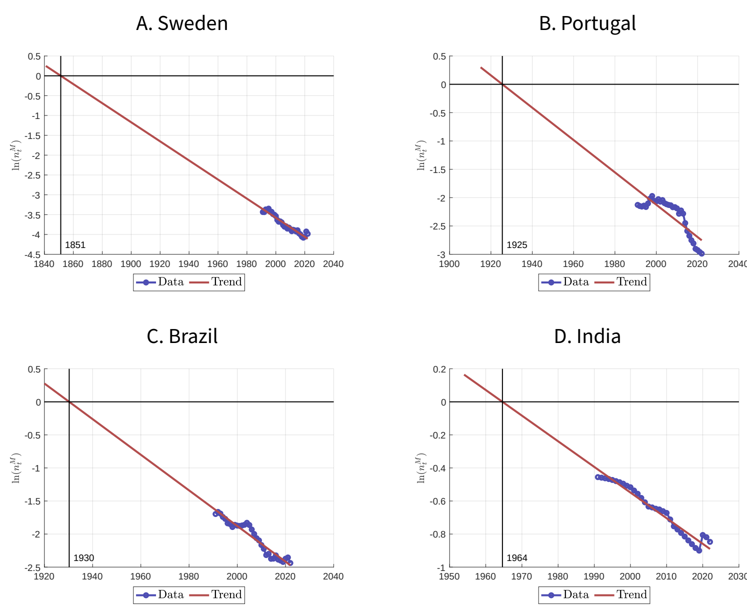
SOURCE: World Bank and Delventhal, Fernández-Villaverde, and Guner (2021).

Since the onset of economic transition is determined using only data on agricultural employment, we validate our estimate of the onset using GDP data. We find that the trend in per capita GDP growth is higher after the onset of transition relative to before.

3.1 Onset of Transition

We use recent data on the share of agricultural employment and determine the onset of transition by estimating β_0 and β_1 in equation (7) and computing t^* from equation (8). The data on agricultural employment are from the World Bank for the years 1991 to 2022. While a longer time series is available for Sweden, we use the sample from 1991 to 2022 to help us compare the implications across the four countries.

Figure 2
Onset of Economic Transition from Malthus to Solow



NOTE: The figure plots the log of the share of agricultural employment from 1991 to 2022.
SOURCE: World Bank and authors' calculations.

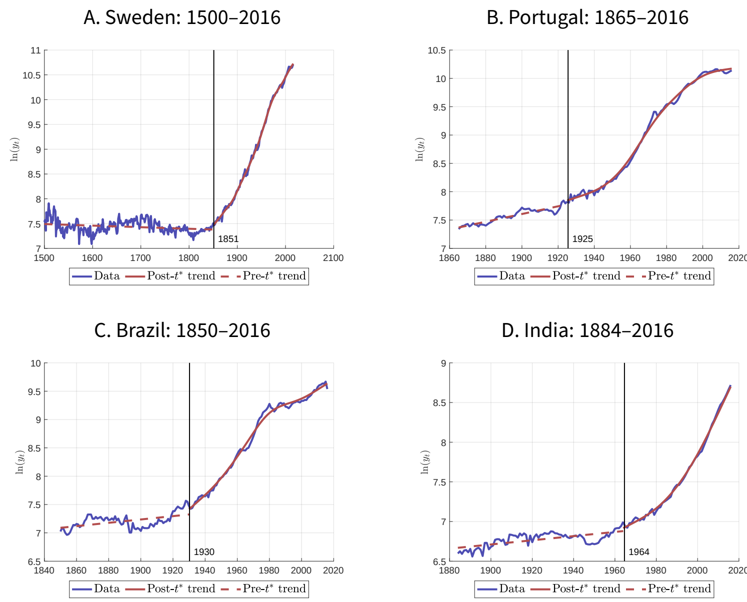
Figure 2 illustrates the onset of the transition for the four countries. Our estimates of t^* are 1851 for Sweden, 1925 for Portugal, 1930 for Brazil, and 1964 for India.

3.2 Per Capita GDP

To validate our estimate of the onset of economic transition, we examine per capita GDP data for the four countries, using data from Delventhal, Fernández-Villaverde, and Guner (2021). Figure 3 illustrates the time series of per capita GDP along with its Hodrick-Prescott trend. As the figure shows, the trend in per capita GDP before t^* is lower than the trend after t^* for each country.

Figure 3

Per Capita GDP



NOTE: The figure plots the log of per capita GDP. The pre-t^* trend is based on the best linear fit of the time series. The post-t^* trend is based on the Hodrick-Prescott filter with smoothing parameter 2,000.
SOURCE: Delventhal, Fernández-Villaverde, and Guner (2021) and authors' calculations.

4. CONCLUSION

In our model, a single good can be produced using labor as the sole input to two technologies: Malthus (diminishing returns) and Solow (constant returns). TFPs and total labor endowment are exogenous. We show that employment in the Malthus technology is sufficient to determine the onset of economic transition. Quantitatively, we estimate the onset of transition for Sweden, Portugal, Brazil, and India using recent data on agricultural employment. Although our estimate does not rely on GDP data, it is consistent with lower growth before the onset of transition and higher growth afterward.

Our model is one of economic transition, not demographic transition, as the processes for TFPs and total labor are exogenous. Endogenizing one or more of these processes could deliver additional testable implications. However, richer frameworks must still demonstrate the quantitative importance of recent agricultural employment for economic transition.

A lesson from our model is for the well-known lack of cross-country convergence in per capita GDP. One reason for this lack of convergence could be that some countries transitioned from Malthus to Solow later, while others transitioned earlier. If reliable historical GDP data were available for all countries, then we could test whether today's poor countries have more recent transition dates compared with rich countries. Our approach provides an alternative that does not require such data. A few recent observations on the share of agricultural employment suffice, and these data are easily available for many countries. Using the level and rate of decline of this share, we can determine the onset of transition and hence examine how much of the lack of income convergence is due to late versus early transitions.

REFERENCES

Becker, Gary S., Kevin M. Murphy, and Robert Tamura. 1990. Human Capital, Fertility, and Economic Growth. *Journal of Political Economy* 98 (5, Part 2): S12–S37.

Delventhal, M J, J Fernández-Villaverde, and N Guner. 2021. Demographic Transitions Across Time and Space. *NBER Working Paper Series,* no. 29480.

Galor, Oded, and David N. Weil. 2000. Population, Technology, and Growth: From Malthusian Stagnation to the Demographic Transition and Beyond. *American Economic Review* 90 (4): 806–828.

Goodfriend, Marvin, and John McDermott. 1995. Early Development. *American Economic Review* 85 (1): 116–133.

Hansen, Gary D., and Edward C. Prescott. 2002. Malthus to Solow. *American Economic Review* 92 (4): 1205–1217.

Lucas, Robert E. 2002. *Lectures on economic growth.* Harvard University Press, Cambridge, MA.

Ravikumar, B., and G. Vandenbroucke. 2025. On the transition to sustained growth: The importance of recent agricultural employment. *Review of Economic Dynamics* 58:101291. https://doi.org/https://doi.org/10.1016/j.red.2025.101291.

Tamura, Robert. 2002. Human capital and the switch from agriculture to industry. *Journal of Economic Dynamics and Control* 27 (2): 207–242.