Weather, fertility, and land: land curse in economic development in a unified growth theory

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August 2011

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Abstract

We consider fertility choice and weather in analyzing the effect of farmland abundance in economic development. We find that quality-adjusted agricultural land abundance may confer a type of "resource curse", in that it prolongs the tenure of an economy in the Malthusian regime. This lends new insights to Unified Growth Theory (Galor, 2011) by elucidating a particular determinant of the differential timing of the transition from Malthusian stagnation to industrialization. Moreover, opposite to the Matsuyama (1992) model, good weather is found to be a blessing for a small open economy, while it is a curse for a closed economy.

JEL Classification: O13; O41; O53; Q15

Keywords: Weather; Fertility; Quality-adjusted Farmland per capita; Quality-adjusted Farmland Abundance Curse

*I thank seminar participants at the Canadian Economics Association Annual Meeting in Vancouver, the UBC macro-international seminars and the TARGET student workshop. I am especially grateful to Paul Beaudry, Giovanni Gallipoli, Ashok Kotwal, Amartya Lahiri for valuable critiques and discussions on the original version of my paper whose empirical part (the main part) has been put into another pure empirical paper.

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1 Introduction

According to Unified Growth Theory (Galor, 2011),[1] the contemporary distribution of the standard of living across countries, and, possibly, across regions within countries, can be explained by the differential timing of the transition from an agricultural epoch of Malthusian stagnation in income per capita to a modern industrialized era of sustained economic growth. In this paper, we are concerned with a particular determinant – agricultural resource abundance – in causing the differential timing of the transition from stagnation to growth and, thus, the contemporary distribution of the standard of living. However, whether agricultural resource abundance is a blessing for industrialization[2] generates controversy in the literature. One view is that agricultural advantage is good for industrialization (Rostow, 1960; Nurkse, 1953).[3] Another view argues that more agricultural resource is a curse for small open economies, although it is a blessing for closed economies (Matsuyama, 1992). Yanagawa (1996) shows that the answer to the question is not unique.[4]

The controversy, theoretically, lies in whether agricultural resource abundance can allow one economy to solve the food problem so as to release resources from the agricultural to the manufacturing sector that is the engine of modern growth (see Schultz, 1953; 1968; Rostow, 1960; Nurkse, 1953). However, existing theories on agricultural resources neglect fertility choice and weather. People's fertility choice and thus total population respond to agricultural resources that are essential for the production of survival good, food. How fertility responds to agricultural resources (e.g., Malthus, 1798; Strulik and Weisdorf, 2008) would determine whether more resources could be released from agriculture. We may get different predictions depending on how to define agricultural resource abundance: in absolute amount or in per capita term. This also decides how one empirically measures agricultural resources in testing theories.

To incorporate the role of fertility, we use the unified growth theory to study the role of agricultural resource abundance in causing the differential timing of the transition from stagnation to growth. We show that quality-adjusted agricultural land abundance – detailed later – really does confer a type of "resource curse," in that it prolongs the tenure of an economy in the Malthusian regime. Resultantly, we lend new insights to

[1]See Galor (2011) for a thorough survey of the literature on unified growth theory. Because of his excellent discussion of it, we shall omit detailed references to the literature.

[2]In this paper, industrialization does not merely refer to industrial revolution. Industrialization here refers to the structural transformation in which the sectoral composition of economic activity shifts from agriculture towards industry and services (see Kuznets, 1966).

[3]Nurkse (1953) and Rostow (1960) argue that an increase in agricultural productivity is necessary for industrialization. They suggest that increases in agricultural resource abundance allow solving the food problem so that resources can be released from the agricultural to the manufacturing sector.

[4]Recently, Galor et al. (2008) emphasize that equality vs. inequality of the distribution of land ownership instead of abundance vs. scarcity of land matters for development.

Unified Growth Theory by elucidating agricultural resource abundance as a particular determinant of the differential timing of the transition from stagnation to growth and, thus, the contemporary distribution of the standard of living.

Specifically, we build a two-sector model of farmland resources with fertility choice and weather based on Matsuyama (1992) and Strulik and Weisdorf (2008). We will discuss possible extensions in the line of human capital accumulation by augmenting parental preferences to allow for a quality-quantity trade-off over children (see, e.g., Becker and Lewis, 1973; Galor and Weil, 2000). Our model is a two-period overlapping generation one with two sectors: agriculture and manufacturing. The engine of growth is learning-by-doing in manufacturing as in Matsuyama. People have quasi-linear preference on children as in Strulik and Weisdorf.

If besides the Malthusian preventive check in Strulik and Weisdorf (that is, fertility only responds to the relative price of food that is determined by the amount of farmland), people's taste for offspring is not directly affected by weather, then the main predictions of the model would be the same as those based on Matsuyama: there is a land curse in a small open economy, and good weather would also be a curse for the small open economy. If besides the Malthusian preventive check in Strulik and Weisdorf, people's taste for offspring is directly decreased by weather, then the main predictions of the model would remain similar to those based on Matsuyama.

If besides the Malthusian preventive check, people's taste for offspring is directly increased by weather given Strulik and Weisdorf's argument that people's taste for children depends on latitude and weather is one important geographical characteristic of latitude. The model shows that the relative price of food is negatively related to per capita farmland. Higher per capita farmland is a curse for a small open economy because it decreases the relative price of food and this way generates comparative advantage in agriculture. In contrast, it is a blessing in a closed economy. These are also predicted by Matsuyama (1992). The model, however, has new predictions concerning the role of weather in growth and the channel for weather to impact growth. In a closed economy, a good weather shock increases farmland (quantity and quality). This is initially a blessing because the relative price of food would drop, which is good for industrialization as argued by Rostow (1960) and Nurkse (1953). Subsequently, fertility rate will increase. Due to the Malthusian preventive check and weather's direct effect on people's taste for children, fertility will increase more than the farmland, which concurs with Malthus (1798). This results in lower per capita farmland than before the shock, which causes the relative price of food to be higher than before the shock. The higher relative price of food hurts industrialization. Hence, a good weather shock is a curse in a closed economy. However, when the economy is small and open, the higher relative price of food from lower per capita farmland results in comparative disadvantage in agriculture. By specializing in manufacturing, the small open economy enjoys the blessing from good weather. It is neither population nor farmland, instead it is per capita farmland (farmland divided by population) the channel through which good weather positively promotes industrialization.

Are our results robust to extensions of the consideration of human capital accumulation by augmenting parental preferences to allow for a quality-quantity trade-off over children (e.g., Becker and Lewis, 1973; Galor and Weil, 2000)? As discussed later on, the results would hinge on structural parameters on the production function and parental preference. Although these extensions would be important, contradicting predictions may be inevitable. Therefore, we expect future rigorous empirical studies to check whether our theoretical predictions are supported by data. And our model provides guidance for relevant empirical analysis, as detailed in section 3.2.

As is known to all, four Asian tigers and the People's Republic of China have achieved impressive growth in the past several decades. It is also shown that the regional growth inequality among those economies also arouses attention. For instance, Demurger et al. (2002) show that the difference in annual growth rates between the fastest and slowest growing provinces in China over the period of 1979-1998 is 6.2 percentage points. The success of these economies usually began with the land reform in agriculture that emphasizes the equal distribution of land. However, even if land is equally distributed for fast industrialization, the regions within those economies may vary in land abundance, which may cause divergence in growth performance in the process of development. This regional growth inequality comes from differences in comparative advantage and specialization due to variation in the natural endowment of land instead of the distribution of land, which justifies the real world relevance of our theoretical analysis.

The rest of the paper proceeds as follows. Section 2 describes and solves the model. Section 3 discusses possible extensions and the relevance to empirics. Section 4 concludes.

2 A Two-Sector Model of Endogenous Growth with Fertility and Weather

We build our model following Matsuyama (1992) and Strulik and Weisdorf (2008). We study a small open economy that does not affect prices in other countries. The small open economy consists of two sectors: agriculture and manufacturing. Let p_t denote its relative price of food (the price of manufactured goods is 1). Farmland is included as one input of agricultural production.[5] The population size of the small open economy is l_t. Labor is assumed to be immobile across countries.

2.1 A bench mark model with fertility choice but no weather

It is a two-period overlapping generations model. The preference structure follows Strulik and Weisdorf (2008). People consume 1 unit of food only when young. Production and

[5]Farmland in this paper mimics the agricultural productivity in Matsuyama (1992).

reproduction assumed to be asexual take place when old. Population evolves according to $l_{t+1} = n_t l_t$, where n_t is the gross rate of population that is assumed to equal fertility rate. For a representative agent who is born at time t, her preference is given by $U_t = m_t + \gamma ln\left(n_t\right)$, where m_t is the amount of manufacturing good she consumes and n_t is the number of children she reproduces when old. γ governs her taste for children.[6]

The representative agent's budget constraint is $p_t n_t + m_t = w_t$, where w_t is his income (in terms of manufactures). The demand for offspring is

$$n_t = \frac{\gamma}{p_t}. \tag{1}$$

This is just Malthus' (1978) preventive check hypothesis in Strulik and Weisdorf (2008).

The production side of the model follows Matsuyama (1992). Manufacturing employs labor only, while agriculture uses both labor and farmland for production:

$$\begin{aligned} Y_t^M &= M_t F\left(\theta_t\right) && (2) \\ Y_t^A &= \frac{\tau_t}{l_t} G\left(1-\theta_t\right) && (3) \end{aligned}$$

where θ_t is the fraction of labor employed in manufacturing and τ_t is the endowment of farmland (the product of the quantity and the quality of farmland), and l_t is total population.[7] We assume: $F(0) = G(0) = 0$; $F', G' > 0$; $F'', G'' < 0$.

Following Matsuyama (1992), we assume the engine of growth is learning-by-doing in the manufacturing sector. And the learning-by-doing does not spill over across countries. Manufacturing productivity M_t is endogenous and evolves over time according to

$$M_{t+1} - M_t = \dot{M}_t = \delta Y_t^M \Rightarrow \frac{\dot{M}_t}{M_t} = \delta F\left(\theta_t\right) \tag{4}$$

2.1.1 The equilibrium of the world economy

The world economy differs from the small open economy only in that its farmland endowment and population are T_t and L_t, respectively. The consumers in the world share the same preference, so the equilibrium of the world economy mimics that of a representative closed economy. Competition in labor market implies[8]

[6] γ makes sure that agriculture always exists. Its role is the same as the subsistence level of consumption (also denoted as γ) in Matsuyama (1992).

[7] We can write the production functions in terms of the amount of labor as: $Y_t^A = G\left(L_A, Land\right)$ and $Y_t^M = M_t F\left(L_M\right)$, where L_A and L_M are the amount of labor in agriculture and manufacture respectively. Suppose G and F are homogenous of degree 1, then we can divide both of them by total labor, L. And the properties of the model will be the same, but we can get agricultural output as a function of θ_t and per capita land.

[8] The follows Matsuyama (1992). Matsuyama argues that, the wage-gap between manufacturing and agriculture and the labor migration from agriculture to manufacturing may be substantial in reality, but they would not affect the predictions of the model and are assumed away for simplicity.

$$p_t \frac{T_t}{L_t} G' \left[(1-\theta_t) \right] = M_t F' (\theta_t) \tag{5}$$

One can observe that, the relative price of food depends on per capita farmland, which is different from Matsuyama (1992) who predicts that the relative price of food depends on total farmland (given fixed population). The price of food depends on the relative (i.e. per capita) endowment of farmland makes sense. We can use the following case. If two identical countries got merged into one, the relative price of food should be same as before, all else equal. But Matsuyama's model would predict that the merger of two identical countries would decrease the relative price of food, which is unlikely.[9]

The market clearing condition for the food market implies $Y_t^A = n_t L_t$, where $n_t L_t$ is the total demand for food. Using equation (3), we have

$$\frac{1}{G(1-\theta_t)} = \frac{T_t}{n_t L_t^2}. \tag{6}$$

Equations (1), (5) and (6) govern the equilibrium of the model, from which we can solve the three unknown variables of p_t, n_t and θ_t. We can get

$$\frac{G'(1-\theta_t)}{G(1-\theta_t)} \cdot \frac{1}{M_t F'(\theta_t)} = \frac{1}{\gamma L_t}. \tag{7}$$

Depending on the functional forms that determine how the relative price of food to change, the model predicts two long-run equilibria. One mimics those in Strulik and Weisdorf (2008) and Jones (1995): there is no long-run productivity growth, with different mechanism. In this equilibrium, the population explodes given initially $n_t > 1$, so we need the whole labor force to work in agriculture to support the exploding population. Given the food market clearing condition (the maximum of food the land can produce), in the end, population growth drops to unity, and θ_t decreases to zero (that is, no productivity growth in manufacturing, $\delta F(0) = 0$). The second has a decreasing rate of population growth (n_t decreases over time) beginning from $n_t < 1$. As population shrinks, we need smaller share of population working in agriculture. In the end, θ_t converges to one, and we have the maximum rate of productivity growth: $\delta F(1)$.

In the transitional path, the left-hand-side of equation (8) is a monotonically increasing function of θ_t, so equation (7) has a unique solution for θ_t (θ_t^*). The world manufacturing productivity grows at the rate of $\delta F(\theta_t^*)$.

2.1.2 Per capita farmland endowment and economic growth

It is assumed that both agricultural and manufactured goods are traded as homogenous

[9] Matsuyama (1992) has a fixed population in his model, so he discusses that agricultural productivity is affected by land endowment. Therefore, land endowment there affects the relative price of food. Without considering fertility and population, the land endowment in his model is open to interpretation.

goods with equal prices in all countries. The other countries, excluding the small open economy, consist of the rest of the world. Taking the ratios of each side of equation (5) and that of the rest of the world to remove the relative price of manufacturing good, equation (5) becomes

$$\frac{F'(\theta_t)}{G'[(1-\theta_t)]} = \frac{(\tau_t/l_t)\, M_t^*}{(T_t/L_t)\, M_t} \frac{F'(\theta_t^*)}{G'[(1-\theta_t^*)]} \tag{8}$$

where the variables with a star superscript or in capital letters denote the world (or the rest of the world). At the initial period, $t = 0$, all else equal, it is obvious that

$$\theta_0 \lesseqqgtr \theta_0^* \text{ if and only if } \frac{(T_0/L_0)}{M_0^*} \lesseqqgtr \frac{(\tau_0/l_0)}{M_0}. \tag{9}$$

At $t = 0$, we assume that the rest of the world differs from the small open economy only in their amount of per capita farmland, that is, their manufacturing productivity is assumed to be equal: $M_0^* = M_0$. According to equation (5), if the small open economy has higher per capita farmland, its relative price of food will be lower. Hence it will have comparative advantage in agriculture and specialize in it. In other words, the small open economy will have a smaller share of labor employed by manufacturing than the rest of the world. Differentiating equation (8) further shows that the initial comparative advantage of the small open economy will intensify over time, and the manufacturing employment share of the economy will drop faster. Given the engine of growth is learning-by-doing in manufacturing, the growth rate of the economy will be even lower when compared with those economies that have lower initial amount of per capita farmland.

Until now, the model, except for the long-run equilibria, predicts the same as Matsuyama (1992). Suppose initially there is a positive shock in farmland endowment, τ_t. Before the fertility rate can change, according to equation (5), this would cause lower relative price of food (suppose price adjusts faster than fertility). But this turns out to be a curse because, according to equation (9), the small open economy would have comparative advantage in agriculture. Then, fertility rate responds. We combine equations (1) and (5) to eliminate the relative price of food:

$$n_t = \frac{G'(1-\theta_t)}{M_t F'(\theta_t)} \cdot \frac{\tau_t}{L_t} \cdot \gamma \tag{10.1}$$

Following an increase in farmland, the fertility rate tends to increase one-for-one (the middle term in the right-hand-side (RHS) of equation 10.1). However, having comparative advantage in agriculture causes θ_t to decrease. This decreases the first term in the RHS of equation (10.1) since $F'' < 0$, $G'' < 0$ and M_t is increasing. This tends to lower fertility rate. In sum, the increase in fertility is smaller than that in farmland, so the small open economy will always have higher per capita farmland than the rest of world. Hence, it will always have comparative advantage in agriculture. More total farmland is a curse, as predicted by Matsuyama (1992), and it does not matter whether one differentiates between total and per capita farmland. Therefore, if we model fertility choice fully as a Malthusian preventive check as in Strulik and Weisdorf (2008), the model predicts the same as the Matsuyama (1992) model that neglects fertility choice.

Although weather will be introduced in next section differently, it is desirable to discuss how weather impacts the economy if fertility choice is fully a Malthusian preventive check. In this case, a good weather shock hurts the industrialization of a small open economy, while it is a blessing for industrialization for a closed economy. For a small open economy, it can be shown that the increase in fertility will be lower than that in farmland, following a good weather shock. Therefore, the small open economy will always specialize in agriculture, which is bad for its development. For a closed economy, a good weather shock also increases the farmland. This is initially a blessing because the relative price of food will drop, which is good for industrialization as argued by Rostow (1960) and Nurkse (1953). Subsequently, although the fertility rate increases due to the Malthusian preventive check (lower relative price of food, p_t), it increases less than the amount of farmland, resulting in lower relative price of food. This is still good for industrialization.

The following proposition summarizes the discussions made above about farmland, fertility choice, weather and comparative advantage.

Proposition 1 *All else equal, given an increase in farmland, initially, a small open economy has higher farmland per capita. This results in comparative advantage in agriculture. If fertility choice is fully a Malthusian preventive check as in Strulik and Weisdorf (2008), subsequently, the increase in fertility will be smaller than that in farmland. Therefore, the small open economy will always have higher farmland per capita (lower relative price of food) and thus comparative advantage in agriculture. Then a good weather shock will hurt the industrialization of the small open economy, while it promotes the industrialization of a closed economy.*

2.2 Weather, fertility rate, per capita farmland, and growth

It is obvious that the quantity and quality of farmland would be directly affected by weather conditions. Good weather conditions (like more rainfall and higher temperature) would directly raise the quantity and quality farmland. Therefore, it is natural for us to assume that $\tau_t = \tau_t(W_t)$ where W_t stands for good weather, with $\tau' > 0$. That is, better weather conditions increase the amount of farmland. Better weather (more rainfall and higher temperature) is good for the quality and quantity of land within some range. It is also possible that rainfall may be too much and temperature may be too high for agriculture as is case in tropical African countries studied by Bloom and Sachs (1998). Therefore, bad weather in our paper refers to situations in which there is little rainfall and low temperature and those in which there is too much rainfall and too high temperature. Since for the extreme cases in which there is too much rainfall and too high temperature, one only needs to assume that $\tau_t = \tau_t(W_t)$ where W_t stands for bad weather like too much rainfall and too high temperature, with $\tau' < 0$. In the following, we mainly focus on analyzing $\tau' > 0$. The predictions would be straightforward with $\tau' < 0$, which is omitted.

What is less known is the effect of weather on fertility choice. There is no established empirical evidence on the relationship between weather/climate and fertility rate. Therefore, we differentiate among three cases for $\gamma = \gamma(W_t)$: (1) $\gamma' = 0$, which means there is no direct effect of weather/climate on fertility choice; (2) $\gamma' < 0$, which means better weather conditions directly decrease people's desire for more children; (3) $\gamma' > 0$, which means better weather conditions directly increase people's desire for more children. Strulik and Weisdorf (2008) argue that the variation in the taste for children may be related with latitude. One important feature of latitude is weather condition. The following examines the relationship between weather and economic development, and that between per capita farmland and economic development.

The first case (i.e., $\gamma' = 0$) has already been studied in the previous section. The predictions have been summarized in proposition 1. The predictions of the second case (i.e., $\gamma' < 0$) would be the same as those (in proposition 1) in the first case. A positive weather shock has two opposing effects on fertility rate. The first effect is through increasing the amount of farmland. This agricultural advantage, according to equation (5), will cause the relative price of food (p_t) to decrease. This, by decreasing the denominator in equation (1), will increase fertility rate one-for-one. The second effect is that better weather will change people's taste for children by making them demand for less offspring (γ decreases). This will decrease the numerator in equation (1), which decreases fertility rate. Therefore, the increase in fertility rate would be smaller than that in farmland, yielding higher per capita farmland for the next period than that before the shock. Higher per capita farmland means a unit area of farmland needs to support fewer people, which, again according to equation (5), will cause the relative price of food to decrease. This will intensify the initial trade pattern for this small open economy: it will continue to have a comparative advantage in agriculture. But this turns out to be a curse since the engine of growth is learning-by-doing in manufacturing. More total farmland is a curse, as predicted by Matsuyama (1992), and it does not matter whether one differentiates between total and per capita farmland. Therefore, it does not matter whether we model fertility choice fully as a Malthusian preventive check as in Strulik and Weisdorf (2008) as in the first case or as that better weather conditions directly decrease people's desire for more children (i.e., $\gamma' < 0$), the model predicts the same as the Matsuyama (1992) model that neglects fertility choice. Moreover, in either case, a good weather shock hurts the industrialization of a small open economy, while it is a blessing for a closed economy.

For the third case (i.e., $\gamma' > 0$), the following proposition presents the new predictions concerning weather, farmland, fertility choice and comparative advantage.

Proposition 2 *All else equal, following a positive shock in weather, initially the amount of farmland will increase. This results in comparative advantage in agriculture for the small open economy. If besides Malthusian preventive check as in Strulik and Weisdorf (2008), people's taste for children is directly increased by weather, subsequently, the increase in fertility will be larger than that in farmland. Resultantly, the population pressure causes the small open economy to have lower farmland per capita (higher relative price of food) and thus comparative advantage in manufacturing. A good weather shock promotes its economic development, and per capita farmland is the precise channel at play. In contrast, in a closed economy, a good weather shock is a curse for its industrialization.*

Proof. Suppose originally the small open economy is identical to the world economy (including per capita farmland and the employment share of manufacturing). We begin our analysis with an exogenous shock in weather condition, W, and we suppose the shock increase W_0 to $2W_0$. Upon impact, suppose price adjusts faster than fertility, then the small open economy will have comparative advantage in agriculture since it has lower relative price of food. Subsequently, to see clearly how the economy of a small open economy relatively evolves over time, that is, to see how fertility responds to the shock in weather, we again combine equations (1) and (5) to eliminate the relative price of food:

$$n_t = \frac{G'(1-\theta_t)}{M_t F'(\theta_t)} \cdot \frac{\tau(W_t)}{L_t} \cdot \gamma(W_t) \tag{10.2}$$

which is similar to equation (10.1). However, since $\gamma' > 0$, equation (10.2) shows that the increase in fertility rate ($\tau(2W_0) \times \gamma(2W_0)$) is larger than that in the amount of land ($\tau(2W_0)$), following a double in weather condition. The positive weather shock has two effects on fertility rate. One is through increasing the amount of farmland. This agricultural advantage, according to equation (5), will cause the relative price of food (p_t) to decrease. This, by decreasing the denominator in equation (1), will increase fertility rate one-for-one. The other is that better weather will change people's taste for children by making them demand for more offspring (γ increases). This will increase the numerator in equation (1), which further increases fertility rate. The increase in fertility rate is larger than that in farmland, yielding lower per capita farmland for the next period than that before the shock. Lower per capita farmland means a unit area of farmland needs to support more people, which, again according to equation (5), will cause the relative price of food to increase. This will reverse the initial trade pattern for this small open economy: it will have a comparative disadvantage in agriculture. But this turns out to be a blessing since the engine of growth is learning-by-doing in manufacturing.

The above discussion depends on the adjustment speed of fertility and that of θ_t. It is helpful to compare with the case of $\gamma' = 0$, that is, weather has no direct effect on fertility, in subsection 2.1.2. Following a double in weather conditions, the increase in fertility is smaller than that in farmland, which makes the small open economy always have higher per capita farmland than the rest of world. Hence, it will always have comparative advantage in agriculture. In contrast, with $\gamma' > 0$, as long as the effect from the change in θ_t on fertility rate does not dominate that from γ, the small open economy would soon have lower per capita farmland than the rest of the world because its fertility increase more than that in farmland. This yields comparative disadvantage in agriculture for the small open economy: a blessing from better weather.

Now it is important to differentiate between total farmland and per capita farmland. Although the amount of total farmland increases following the positive weather shock, there is no total farmland curse. This is because subsequent population increases more than total farmland, which results in lower per capita farmland. By specializing manufacturing, the small open economy has higher growth.

For a closed economy, a good weather shock is initially a blessing as discussed. However, subsequently, the fertility rate will also increase due to the Malthusian preventive check (lower relative price of food, p_t) and weather's direct effect on people's taste for children (higher γ). Fertility increases more than the amount of farmland, resulting in lower per capita farmland (we term this as population pressure). This concurs with Malthus (1798, ch.1, p.13)

> The power of population is indefinitely greater than the power in the earth to produce subsistence for man. Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetical ratio. A slight acquaintance with numbers will show the immensity of the first power in comparison with the second.

Next period, per capita farmland will be lower than that before the weather shock, which through competition in labor market yields higher relative price of food. In other words, the farmland needs to feed a relatively larger population. Food demand exceeds food supply, pushing up the relative price of food to be higher than before the shock. This hurts industrialization because fewer resources can be released from agriculture to the manufacturing sector (Nurkse, 1953; Rostow, 1960). Therefore, a good weather shock is a curse in a closed economy. The prediction of a good weather curse in a closed economy is not surprising. Clark (2007, ch. 1) describes how the Malthusian logic applies to the pre-1800 Easter Island society,[10] a closed economy that may collapse due to population pressure. Moreover, people might fight for the wind-fall from good weather (Miguel et

[10] de la Croix and Dottori (2008, p. 28) state: "Easter Island had a rising population and a prosperous civilization until about the XVth century, after which it declined sharply. The most popular sign of that past glory is moai, the enormous statues carved in stone and erected all over the island by the inhabitants. By the XVIIIth century,..., the population had been decimated. Easter Island is therefore an example of how a closed system can collapse, but what exactly happened is still an unresolved matter."

al., 2003), causing social conflict. Social conflict has been shown to hurt development (Easterly and Levine, 1997; Rodrik, 1998). Together, they imply that good weather hurts growth through institutional conflict. In contrast, the mechanism in our model mimics Malthus' (1798) population pressure and directly shows good weather hurts growth in a closed economy where institutional conflict is non-existent. Q.E.D.

To recap, given $\tau' > 0$ (i.e., better weather conditions increase the amount of farmland) and $\gamma' > 0$ (i.e., better weather conditions directly increase people's desire for more children), for a small open economy, higher per capita farmland is a curse because it decreases the relative price of food and this way generates comparative advantage in agriculture. Better weather lowers per capita farmland because it increases fertility rate more than it raises the amount of farmland. Lower per capita farmland (i.e. higher population pressure) increases the relative price of food and thusly causes the small open economy to have comparative advantage in manufacturing. It is neither population nor farmland via which weather impacts growth. Their combination – per capita farmland – is the channel through which weather impacts growth. And in this case, a good weather shock promotes the economic development of a small open economy, and per capita farmland is the precise channel at play. For a closed economy, a good weather shock would be a curse for its industrialization.

In contrast, when $\gamma' = 0$ or $\gamma' < 0$ (i.e., better weather conditions either have no effect on people's desire for more children or directly decrease people's taste for more children), better weather increases per capita farmland because it increases fertility rate less than it raises the amount of farmland. This would result in higher per capita farmland. In a closed economy, higher per capita farmland (i.e. lower population pressure) decreases the relative price of food, which relieves the "food problem" (Schultz, 1953, 1968) and thereby promotes industrialization. A good weather shock would be a blessing for the industrialization of a closed economy. However, in a small open economy, higher per capita farmland decreases the relative price of food and thereby causes the small open economy to have comparative advantage in agriculture. It is either the amount of farmland or population density the channel through which weather impacts growth. And in either case, a good weather shock retards the economic development of a small open economy.

3 Possible Extensions and Empiric Implications

3.1 Possible extensions

The previous sections generate the link between weather and fertility by assumption. Ideally, we can model it as an equilibrium outcome as is done in most recent micro-founded neo-Malthusian models (see, e.g., Ashraf and Galor, forthcoming). The simplest way to implement this would be to allow for a land-quality "technology" parameter in the agricultural production function that responds positively to weather conditions. A positive weather shock would then cause an increase in the marginal product of labor economy-wide (i.e., in both sectors of the economy due to the competitive nature of the labor market), and the resultant increase in household income would confer an income effect on the desired number of children. The one issue that one will need to be aware of from implementing this strategy is that the positive weather shock will result in an immediate inter-sectoral reallocation of labor away from manufacturing to agriculture until wage rates are equalized across sectors. This will tend to dampen our result in equation (10.2) that, following a positive weather shock, the increase in fertility is larger than the increase in farmland, but we think the desired result could be restored with reasonable assumptions on functional properties.

As one can see, many theoretical results in the third case hinge critically on its Malthusian feature that fertility rates respond positively to good weather conditions due to the decline in the relative price of food (that arises from an expansion in farmland per capita). However, it is important to examine whether the results are robust when we account for the importance of human capital accumulation during the process of industrialization, as Unified Growth Theory suggests we should. Specifically, parental preferences are augmented to allow for a quality-quantity trade-off over children (see, e.g., Becker and Lewis, 1973; Galor and Weil, 2000) and manufacturing production is more realistically modeled as being skill-intensive. Then it may not necessarily be the case that the fertility rate will increase following a good weather shock. In the closed-economy case, the initial beneficial effect of the shock on industrialization (as a result of relaxing food-availability constraints) will continue to persist in contrast to the prediction of the current model. The initial surge in industrialization will raise the demand for human capital, which will, in turn, result in endogenous household substitutions of child quantity for quality. This will not only prevent an increase in population (and thus prevent a lowering of farmland per capita and a concomitant decline in relative food prices, thereby allowing industrialization to proceed), but it will further fuel industrialization due to the resultant increase in the supply of skilled labor. Moreover, given such an augmented model, the predictions for the small open-economy case may be ambiguous. On the one hand, since relative food prices will not necessarily decline following a good weather shock, the agricultural sector may continue to maintain its comparative advantage. As such, good weather may continue to remain a curse for a small open economy. On the other hand, given the initial increase in the demand for skilled workers (due to the expansion of industry), comparative advantage may switch to the manufacturing sector, depending on the complementarity between skilled labor and physical capital in manufacturing and the elasticity of child-quality with respect to household income. Therefore, it is more meaningful to empirically identify whether good weather is a blessing for a small open economy, which is briefly examined in the next section.

3.2 Implication for empirics

Recently, Galor et al. (2008) emphasize that equality vs. inequality of the distribution of land ownership instead of abundance vs. scarcity of land matters for development: "The theory further suggests that some land abundant countries that were characterized by an unequal distribution of land, were overtaken in the process of industrialization by land scarce countries in which land distribution was rather equal." Nevertheless, one can also interpret the phenomenon as a curse from land abundance. Land endowment is entangled with its distribution in real world. Therefore, empirically, it would be ideal to find a natural experiment in which one can control for the distribution of land when examining the role of land abundance in development.

Further, unlike mineral resources that took millions of years to form, agricultural resources are likely to be endogenous. Overcoming their potential endogeneity poses one challenge for empirics. Existing theory neglecting weather cannot predict how weather affects agricultural resource and whether agricultural resource is the channel for weather to impact development. It is, therefore, not clear whether weather provides a valid instrument to overcome the endogeneity of agricultural resource in examining its role in development. According to the third case of our model, weather affects the quantity and quality of farmland as well as people's taste for children. The variation in weather conditions is exogenous to the growth process. Since we have pinned down the channel, per capita farmland, it works on growth, we can empirically test the effect of per capita farmland on growth, using weather conditions as instruments. However, there is a debate over the channel of causality between geography including climate and economic development. Some show that geography directly affects development (Bloom and Sachs, 1998; Sachs et al., 1998). Others focus on the channel and have identified it as past events/institution (Acemoglu et al., 2001; Sokoloff and Engerman, 2000). Given the other potential channels and the possibility that weather may directly impact growth, weather may not be valid as an instrument. This imposes a dilemma for instrumental variable regressions that attempts to overcome the potential endogeneity problem of farmland abundance.

As discussed, without solid empirical evidence on the direct relationship between weather/climate conditions and fertility rate, it is more appealing to resort to empirical work to test the different theoretical predictions. We take the predictions for a small open economy as examples. In the small open economy, as already discussed, Matsuyama (1992), first of all, does not differentiate the two-dimensions of land: quality and quantity, so the curse he predicts could be a quantity one or a quality one. Moreover, Matsuyama neglects fertility choice, which is similar to our first case in which weather has no direct effect on people's taste for children. Therefore, the existence of a land quality curse would favor the Matsuyama model.

In the second case in which weather has a direct negative effect on people's taste for children, the predictions would be the same as if farmland was not affected by weather (although it is not true in real world) and weather affects only people's taste on children. Therefore, it is appealing to check whether population density rather than quality-adjusted farmland per capita is the channel by which weather affects growth. The reciprocal of population density is total land per capita (i.e., total land area of a province divided by its population as in Sachs and Warner, 1997; Stijns, 2000), so a regression with ln(Population Density) is the same as one with ln(total land per capita). The existence of a population density blessing (or a total land per capita curse) in a small open economy would support the second case.

In contrast, to test the third case in which weather has a direct positive effect on people's taste for children, one needs to construct quality-adjusted farmland per capita. This is because in this case, it is neither population nor farmland, instead it is per capita farmland (farmland divided by population) the channel through which weather impacts growth. Quality-adjusted farmland per capita is the product of the area of farmland and the quality of farmland divided by population. This measure is not total area of a province divided by population as in Sachs and Warner (1995) and Stijns (2000) in testing the second case. In addition, they incorporate the quality of land. Previous empirical measures of land overlook the quality of land (Sachs and Warner, 1995; Stijns, 2000). However, a quantity measure of land without controlling for the quality of land would be subject to interpretation problem: a quantity curse could be interpreted as a quality blessing. For instance, Canada and Russia may on average have higher per capita area of farmland. It may be simply because their land quality is low as is the case in Canada and Russia. Nevertheless, the existence of a quality-adjusted per capita farmland curse would support the third case.

If ideally one can find suitable measures for all three cases, one can further put the quality of land, population density, and quality-adjusted farmland per capita in the regressions to test whose estimated coefficient would be significant in promoting economic growth. In so doing, which of the three cases is supported by data would be identified.

4 Conclusions

To examine the role of land abundance in the economic development of a small open economy, we introduce fertility choice into Matsuyama (1992). The model structure follows Strulik and Weisdorf (2008). It is a two-period overlapping generation model with two production sectors: agriculture and manufacturing. The engine of growth is learning-by-doing in manufacturing. People have quasi-linear preference on children. If besides the Malthusian preventive check in Strulik and Weisdorf (that is, fertility only responds to the relative price of food that is determined by the amount of farmland), people's taste for offspring is either directly unaffected or directly decreased by good weather, then the main predictions of the model would be the same as those from Matsuyama. In particular, good weather would be a curse for a small open economy, although it is a blessing for a closed economy. If besides the Malthusian preventive check in Strulik and Weisdorf, people's taste for offspring is directly increased by weather. The model predicts the following.

Higher per capita farmland (i.e. lower population pressure) is good for the industrialization of a closed economy, because the relative price of food that negatively depends on per capita farmland is low and thus more resources can be released from agriculture to manufacturing as argued by Rostow (1960) and Nurkse (1953). In contrast, higher per capita farmland hurts the industrialization of a small open economy. This is because the lower relative price of food causes the small open economy to have comparative advantage in agriculture. Given the source of growth is learning-by-doing in manufacturing, the specialization in agriculture hurts its industrialization. These support Starvianos (2005) who argues that one reason why the west first began modern industrial civilization is that their land resources were relatively scarce comparing to leading agricultural civilizations such as China and India. That is, higher population pressure in the west pushes up the relative price of food, which coupled with international trade causes the west to have comparative advantage in industrial production that is the engine of modern growth.

When weather conditions improve, they directly increase the amount of farmland (quantity times quality), which immediately causes the relative price of food to decrease. Subsequently, the improvement in weather conditions has two effects on fertility. The first is indirect and achieved through the increase in farmland. The increase in farmland will cause the relative price of food to decrease, which will increase fertility rate one-for-one as in Strulik and Weisdorf. The second is weather's direct effect on increasing people's taste on offspring, which increases the fertility rate further. The increase in fertility rate is larger than that in farmland, resulting in lower per capita farmland (higher population pressure). This concurs with Malthus (1798) who argues population increases in a geometrical ratio and subsistence increases only in an arithmetical ratio. Lower per capita farmland causes the relative price of food to increase, resultantly, the small open economy will have comparative disadvantage in agriculture. A good weather shock is a blessing by yielding comparative advantage in manufacturing for a small open economy. Both Matsuyama (1992) who neglect fertility choice and Strulik and Weisdorf (2008) who model fertility choice fully as a Malthus preventive check would predict that better weather would cause the small open economy to have comparative advantage in agriculture. In summary, even if land distribution may be important (Galor et al., 2008), the quantity of land still matters for development.

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