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Pure technology gaps and production predictability☆

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A R T I C L E I N F O

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A B S T R A C T

An average machine lags in terms of productivity and technological advancement behind a cutting-edge machine. This lag was first defined by Cummins and Violante (2002) as the technology gap. Using the vector error correction model, I show that the technology gap is cointegrated with human capital factors, and then decompose it into a long-run trend and a transitory mean-reverting component, which I term as the pure technology gap. I show that the pure technology gap has a predictive power for the aggregate production. Intuitively, a high pure technology gap acts as an economic shock that increases production in the long term due to a higher future productivity level.

1. Introduction

The most technologically advanced machines are on the productivity frontier of an industry. An average machine in use in a given industry will lag behind the ones on the frontier in terms of its productivity and the level of the technological advancement. Following Cummins and Violante (2002), I call the difference in productivity between the cutting-edge and the average machine for a given group of machines "the aggregate technology gap". With time, through industry and geographic spillover effects, the average machine catches up to the frontier machine through the process of efficiency change. Efficiency change may be due to human capital factors (workers learning to better operate the machinery) or physical capital factors (machine parts are upgraded).

In this article I demonstrate that the aggregate technology gap can be decomposed into two parts: a long-term trend component and a transitory mean-reverting component. The decomposition of the technological progress across different vintages of installed capital in order to derive the mean-reverting component of the technological growth (what I will refer to as the "pure technology gap") enables me to use it as a leading indicator of the economic growth.

I demonstrate empirically in the vector error correction model (VECM) setting that the pure technology gap has a predictive power for the future aggregate production levels. I focus on the aggregate technology gaps estimated from two groups of machines: (1) equipment and software; (2) information processing equipment and software. The rationale for investigating the effect of these two groups of machines on the aggregate economy is in their widespread use across different industry sectors.

Intuitively, the closing of the technology gap by industry followers catching up with the leader should change the productivity of the whole industry or perhaps even economy if the machines from a given industry are prevalent. The closing of the technology gap occurs because of the efficiency change process and can be related to both human and physical capital related factors. It is also intuitive to expect that if the technology gap closes or is at least reduced, production and subsequently consumption stream generated by that machine will eventually be higher per unit of time. After a shock to the level of the technology gap, the initial response of the productivity may be negative (if the shock is unfavorable), however due to gradual efficiency change, the final level of productivity will be higher compared to the pre-shock values.

The empirical strategy developed in this article is based on the estimation of the technical change using durable goods price

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indices as in Gordon (1990), and Cummins and Violante (2002). I measure the technical change from quality-adjusted price indices of durable investment goods. Comparing a constant quality price index with an index unadjusted for quality allows me to obtain the estimate of the productivity frontier growth. I measure the productivity of an average machine by dividing the accumulated capital in efficiency units by the installed capital in natural units. The aggregate technology gap is equal to the relative difference between the productivity of the latest vintage and the productivity of an average machine. The aggregate technology gap, a human capital factor, consumption and production levels are then jointly modeled in the VECM. The pure technology gap is a cointegrating equation from the VECM, it has a mean-reverting nature and is stationary by construction. In the baseline specification, I use the return to education as the human capital factor.

The VECM setting comfortably accommodates testing for the predictability of the production levels with the pure technology gap through the short-run adjustment coefficients. I find those coefficients to be significant in most model specifications, which suggests that the pure technology gap predicts future aggregate production. I further confirm this effect by investigating the impulse response functions of the aggregate levels of production and find that the technology gaps have first a transitory negative effect in the short-run and then a permanent positive effect on the levels of production in the long-run. These results are robust to several other model specification, including different human capital factors: share of workers with college education, share of young workers, share of women, and others, as well as including additional variables in the VECM specification.

The findings of this article are significant for two reasons. First, I present a new predictor of the aggregate production: the pure technology gap. The long-run risk literature in asset pricing (e.g. Bansal and Yaron, 2004) which links asset returns to moments of consumption and production growth imposes predictability exogenously and it seems that having a predictor with an economic meaning is a step forward. Second, the technology gaps have possible policy implications, e.g. tax credits for shortening the life of capital and research and development expenditures, and therefore might be useful in the economic policy literature.

2. Empirical methodology

In this section I show the empirical methodology employed in this article. I begin with presenting how to measure the technical change and installed capital productivity. This allows me to next define the aggregate technology gap. I then demonstrate the vector error correction model (VECM) used in the estimation of the production response to the technology gaps.

2.1. Measure of technical change

I use the method of Hulten (1992), and Cummins and Violante (2002)[1] to measure the technical change from investment goods' prices. Hulten (1992) first shows that quality-adjusted price indices can be used to measure the technology gap between the productivity of new vintages and the average practice in the economy.

I will introduce a very simple framework that will help understand the estimation of the technical change from price indices. There is an economy producing final goods k_t that can be accounted for in natural units or in efficiency units h_t, with technology

$$h_t = q_t k_t, \tag{1}$$

where q_t is the Hicks-neutral index of the technology. An example of a natural unit would be a processor. An example of an efficiency unit would be the number of operations per second of a computer processor. Measure q_t is the estimate of the productivity of the last available vintage of capital goods. I have the price of investment goods in efficiency units given by p_t^h and the price of consumption goods in natural units equal to p_t^c. The value of production is the same, irrespective of measurement units[2]:

$$p_t^h h_t = p_t^c k_t, \tag{2}$$

which yields

$$q_t = \frac{p_t^c}{p_t^h}. \tag{3}$$

The estimate of the technical change q_t is further calculated using official NIPA consumption chain-weighted deflator of non-durable and services personal consumption expenditures for p_t^c and the quality-adjusted durable investment goods deflator calculated as in Gordon (1990), Cummins and Violante (2002) and Fisher (2006) for p_t^h.

2.2. Measure of installed capital productivity

In order to measure the technology gap, I need a measure of the productivity of average (installed) capital. Since capital in place is a combination of several past vintages with different characteristics, to obtain one average measure of productivity I will weigh subsequent vintages with their value. Using the notation as in Cummins and Violante (2002), the amount of physical capital available at any time t can be expressed in constant-quality units as:

$$\tilde{k}_t = (1 - d_t^e)\tilde{k}_{t-1} + i_t, \tag{4}$$

where d_t^e is the economic depreciation rate at time t. Weights d_{et}, given by depreciation rates, convert each vintage of investment into new-machine equivalents. Capital stock $\tilde{k}_t$ is then interpreted as the number of new-machine equivalents implied by the stream of past investments, following Hulten (1992).

Each new vintage of capital embodies differences in technical design. For example, a computer manufactured in 2000 will be more productive than a computer made in 1995, even if their accounting values are the same. Because of that, using the regular capital accumulation Eq. (4) understates the true value of successive vintages of productive capital. Vintage of capital introduced at time t is recorded as in Eq. (1). Then I have the capital accumulation equation in efficiency units as:

$$k_t^* = (1 - \delta_t^e)k_{t-1}^* + i_t^*, \tag{5}$$

where δ_t^e is the time-varying physical depreciation rate and i_t^* is the quality-adjusted investment series. I use the physical depreciation rate for the quality-adjusted capital stock as investment is measured in efficiency units, following Gort and Wall (1998). As in Cummins and Violante (2002), the measure of the productivity of

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[1] Many thanks to Gianluca Violante for providing me with the data necessary to estimate the technology gaps.

[2] As in Hulten (1992), change of measurement units will change the price per unit but not the total price. If for example a maximum potential productivity of a $1000 processor is three times higher than that of a processor from last year, then either one processor was purchased or three processors worth $333 each were purchased for the same dollar amount. Actual productivity of the newer processor may be only slightly higher or even initially lower than that of the previous processor.