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More evidence on technological catching-up in the manufacturing sector

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Abstract

Production frontiers for the manufacturing sector are estimated to determine a "country specific" catching-up process of Total Factor Productivity (TFP).TFP gains are gauged at the manufacturing industry level for 14 OECD countries over the 1970-2001 period. Our TFP measure does not assume technical or allocative efficiency which are inherent drawbacks of usual TFP indices. We show that catching-up processes can be very different between sub-periods and across countries. A significant catching-up process was at work in the manufacturing sector between 1970 and 1986 then it overturned over the period 1987-2001. During the first sub-period, the speed of technological catching-up of the euro-zone countries is definitely higher than those of the other European or OECD nations whereas the divergence noted in second sub-period has the same order of magnitude among the three groups.

JEL classification: O33; O40; O47

Keywords: Catching-up; TFP change index; Technology adoption; Production Frontier

1. Introduction

The productivity catching-up hypothesis put forth by Abramovitz (1986) has been recently investigated at the disaggregated level of industries by testing for convergence in Total Factor Productivity (TFP) within sectors across countries[1]. These studies lead to the same major finding that services are driving the aggregate convergence result while tradable sectors as manufacturing showed non significant catching-up process (see for instance Bernard and Jones, 1996a, 1996b; Hansson and Henrekson, 1997).

While these studies take explicitly into account the potential differences between industries in the technological catching-up process, they suffer from one main drawback. The technology level is either computed as a Solow-residual indicator of technology or as a traditional

[1] In this study, we follow Abramowitz's distinction between catch-up and convergence. Catch-up is defined as the narrowing of the productivity gap compared to the leading country, whereas the convergence hypothesis assumes that the productivity gaps narrow among the follower countries as well.

Törnquist index. These choices may then alter or bias the subsequent evaluation of the catching-up mechanism because they assumes technical as well as allocative efficiencies for each country.

A detailed analysis of the comparative productivity performance at sectoral level, and more precisely in the manufacturing sector, is a good way to better understand the mechanism behind the catch-up and convergence process for the economy as a whole. The manufacturing sector plays an important role in the earlier stages of economic growth due to its increasing share of the sector in total production and employment, and its relatively fast rise in productivity). But it also plays an important role in the later stages when manufacturing becomes less important in relative terms, as is presently true for most OECD countries, due to its role of new technology generator and to the associated spill-over effects to other sectors.

Due to the major impact of manufacturing sector on growth, we propose to re-examine the productivity catching-up mechanism across the leading industrial countries in the manufacturing sector by using an empirical strategy which avoids the above-mentioned drawback. The central point of this methodology consists in using a TFP index to determine a parametric-stochastic world production frontier for OECD countries with data spanning the period 1970-2001. We then evaluate the convergence of the estimated technical levels by testing whether technologically laggards start a catching-up process by adopting more advanced production technology from the more efficient countries[2].

Compared to usual studies on technological adoption, one main methodological contribution of our research is to develop a panel data procedure that enables to estimate individual specific processes concerning direction and magnitude of TFP convergence within a set or a sub-set of countries.

Empirical results partly confirm previous findings that no (or even a slow) catching-up effect is at work in the manufacturing sector. However, our results strongly mitigate this finding by showing that the catching-up process is not uniform over time and among different groups of countries. More precisely, while there is strong evidence for technological spreading across OECD and other European nations over the 1970-1986 period, this process of technological

[2] As the analysis is restricted to the case of the main OECD countries, the assumption of technological diffusion appears to be valid since each country in the data set is characterised by rather similar level of "social capabilities" and catch-up potential.

adoption appears to be reversed during the following fifteen years. While within the euro-zone country group, it was more significant and spread out over a longer period (1970-1997).

The paper is organised as follows. Section 2 lays out the basic framework by providing the catching-up model and the measures of TFP gaps between countries. Section 3 reports the empirical results and Section 4 concludes

2. Production Frontier and Total Factor Productivity Convergence

Since the end of the eighties, many empirical studies focusing on international comparison of Total Factor Productivity (TFP) have revealed that differences in technology may contribute to gaps in TFP levels[3]. As TFP is an empirical measure of technology, the concept of TFP-convergence investigates whether countries are able to catch-up in terms of the highest observed TFP levels and how income convergence depends on both TFP growth rates and initial TFP levels. In the same way, we develop a catching-up model based on TFP gaps measured as distances between national production plans to a production frontier constructed for the OECD countries.

2.1. TFP catching-up model

Our catching-up model assumes that relative growth rates of productivity in an industry are determined by specific country catching-up factors. The TFP growth rate of country *i* at time *t* is supposed to be generated by both the lagged technology gap between the desired and observed level of productivity and the common rate of technical change that shifts the production frontier simultaneously for all countries :

$$\ln(q_{it}) - \ln(q_{it-1}) = \lambda_i . \ln\left(\frac{q_{it-1}^d}{q_{it-1}}\right) + g_t \qquad (1)$$

where q_{it}^d is the desired level of TFP for country *i* and g_t the technical progress at time t. We postulate that this desired level of TFP may be considered as the leader's productivity $q_{L,t.}$ located on the production frontier

According to Abramovitz's (1986) concept of «social capabilities», countries may differ in their ability to recognise, incorporate and use available technology. In an attempt to incorporate this concept in the model at hand, we assume that the speed of the catching-up

[3] See Islam (2001) for a review on different approaches to international comparisons of TFP and the issue of convergence

process λ_i is specific for each country[4]. Obviously, the concept of «social capabilities» may encompass many economic factors such as the institutional framework, the level of education, the organisation of firms, international openness, and adjustment costs, so that no single economic variable may adequately measure countries' ability to adopt the technology gap. As suggested by Hultberg et al. (1999), country-specific effects from the production frontier equation should capture country heterogeneity due to social capabilities to adopt available technology.

Equation (1) is rewritten as :

$$\ln(q_{it}) - \ln(q_{it-1}) = -\lambda_i . \ln\left(\frac{q_{it-1}}{q_{Lt-1}}\right) + g_t \qquad (2)$$

Finally subtracting equation (2) from equation of productivity dynamics for leading country L, we obtain:

$$\ln(\tilde{q}_{it}) - \ln(\tilde{q}_{it-1}) = -\lambda_i . \ln\left(\tilde{q}_{it-1}\right) \qquad (3)$$

where a tilde indicates a ratio of TFP level in country *i* to the same variable in the leading country.

Considering the relationship between long-run growth-rates across countries, the difference equation (3) can be solved to yield:

$$\frac{\ln(\tilde{q}_{iT}) - \ln(\tilde{q}_{i0})}{\ln(\tilde{\hat{q}}_{i0})} = \delta_i \qquad (4)$$

with $\delta_i = -\left(1 - (1 - \lambda_i)^T\right)$.

2.2. TFP growth decomposition

Total Factor Productivity indices are usually used to compare production technologies at the aggregate level as well as the sector levels. However these indices measure both technical change and efficiency change. While technical change shifts the production frontier, efficiency change measures the movement of production towards the efficient frontier that can be constructed as the benchmark for all countries in the sample.

The frontier nature of the production function assumes a link between maximal potential output quantities and input quantities. This link is able to capture any productive inefficiency and offers a "benchmarking" perspective. For instance, an economy's performance can be

[4] In that way, productive inefficiency for each country can be incorporated in our catching-up model (cf. point 2.2).

evaluated with respect to both its past experience and the best practices established by other countries[5].

The production technology of a given sector (manufacturing in this study) is represented by the production frontier:

$$y_{i,t}^{F} = g(x_{i,t}, t) \qquad (5)$$

where $y_{i,t}^{F}$ is potential output of this sector in country i at time t ($i = 1 \cdots I$, $t = 1 \cdots T$), x_{it} is the k-dimension vector of inputs and t is time.

The effective level of output of country I at time t ($y_{i,t}$) is then assumed to be given by :

$$y_{it} = y_{it}^{F} \cdot e^{u_{i,t}} = g(x_{it}, t) \cdot e^{u_{it}} \qquad (6)$$

where $e^{u_{i,t}}$ lies in the interval [0 , 1] and measures the efficiency score associated with the effective level of output y_{it} produced with inputs x_{it}.

Differentiating equation 6 with respect to time then leads to

$$\frac{dy_{it}}{y_{it}} = g_x \frac{dx_{it}}{x_{it}} + g_t + \frac{du_{it}}{dt} \qquad (7)$$

where g_x is the elasticity of output with respect to input and g_t is the elasticity of output with respect to time which is assumed to be common to all countries.

According to equation (7) production growth includes three distinct components: changes in input quantities weighted by their respective elasticity ($g_x(dx_{it}/x_{it})$), the shift of the production frontier over time due to the effect of technical change (g_t) and changes in productive efficiency (du_{it}/dt).

Total factor productivity gains (dq/q) are then defined as the amount of output growth not attributable to input quantities variations and can be evaluated as the sum of the technical change effect and of the efficiency change effect:

$$\left(\frac{dq}{q}\right)_{it} = g_t + \frac{du_{it}}{dt} \qquad (8)$$

With a Cobb-Douglas production frontier specification, equation (6) may be rewritten as:

$$\ln(y_{it}) = \alpha + \sum_{k=1}^{K} \beta_k \ln\left(x_{it}^{(k)}\right) + \gamma t + \varepsilon_{it} \qquad (9)$$

[5] For a unified discussion of efficiency and productivity from a production frontier approach and its methodological advantages, the reader can consult Fried, Lovell and Schmidt (1993).

where $x_{it} = \left(x_{it}^{(1)}, \cdots, x_{it}^{(K)}\right)'$ and $\varepsilon_{it} = u_{it} + v_{it}$ where $u_{i,t}$ is the efficiency effect and $v_{i,t}$ an usual iid noise process with zero mean and constant variance.

The Time Varying Effect method proposed by Cornwell, Schmidt and Sickles (1990) is then used to estimate separately the two components of ε_{it}.This method allows the inefficiency component to vary over time by assuming that the efficiency effect u_{it} may be expressed as a quadratic function of time with country-fixed effects:

$$u_{it} = \theta_i^{(0)} + \theta_i^{(1)} t + \theta_i^{(2)} t^2 + v_{it} \quad (10)$$

Where $\theta_i^{(0)}$ is a country-fixed effect, $\theta_i^{(1)}$ and $\theta_i^{(2)}$ are the country-specific parameters measuring efficiency change over time.

Equations (9) added up equation (10) can then be estimated with a generalised within procedure under the two following constraints $\sum_i \theta_i^{(0)} = 0$ and $\sum_i \theta_i^{(1)} = 0$ so as to avoid perfect multi-co-linearity.

With such a specification, the initial TFP level and its growth rate are estimated as a panel data model including both a set of national dummies (to control for the inevitable country heterogeneity due to political and social institutions and to capture some of the Abramovitz ideas of social capabilities) and a set of temporal variables to control for technology adoption fluctuations specific to each country).

Productive efficiency levels can be computed as

$$\mu_{it} = \mathrm{e}^{\hat{u}_{it} - u_t^{\max}} \quad (11)$$

where $\hat{u}_{it} = \hat{\theta}_i^{(0)} + \hat{\theta}_i^{(1)} t + \hat{\theta}_i^{(2)} t^2$ and $u_t^{\max}$ is the value of the efficiency effect in the leader country that is located on the production frontier at time *t*.

By differentiating equation 10 with respect to time, total factor productivity growth may be rewritten as a linear function of time summing technical change and efficiency change components:

$$\left(\frac{dq}{q}\right)_{it} = \gamma + \theta_i^{(1)} + 2\,\theta_i^{(2)} t \qquad (12)$$

The log of Total Factor Productivity can then be written as:

$$\ln\left(q_{it}\right) = \theta_i^{(0} + \left(\gamma + \theta_i^{(1)}\right) t + \theta_i^{(2)} t^2 + v_{it} \qquad (13)$$

from equation (10), the technological gaps in terms of TFP levels between country *i* and the leading country at time *T* and *0* are measured as follows:

$$\ln(\tilde{q}_{iT}) = (\hat{\theta}_i^{(0)} - \hat{\theta}_{L_T}^{(0)}) + (\hat{\theta}_i^{(1)} - \hat{\theta}_{L_T}^{(1)})T + (\hat{\theta}_i^{(2)} - \hat{\theta}_{L_T}^{(2)})T^2 \text{ at time } T \qquad (14a)$$

and

$$\ln(\tilde{q}_{i0}) = (\hat{\theta}_i^{(0)} - \hat{\theta}_{L_0}^{(0)}) \text{ at time } 0 \qquad (14b)$$

where $\hat{\theta}_{L_T 0}, \hat{\theta}_{L_T 1}, \hat{\theta}_{L_T 2}$ are estimated coefficients for the leader at time T and $\hat{\theta}_{L_0 0}$ the logarithmic of the leader's estimated TFP at time 0.

From equations 4, 14a and 14b, we get δ_i and finally an indirect estimate of λ_i as:

$$\hat{\lambda}_i = 1 - \left[1 + \frac{\left(\hat{\theta}_{L_0}^{(0)} - \hat{\theta}_{L_T}^{(0)}\right) + \left(\hat{\theta}_i^{(1)} - \hat{\theta}_{L_T}^{(1)}\right)T + \left(\hat{\theta}_i^{(2)} - \hat{\theta}_{L_T}^{(2)}\right)T^2}{\left(\hat{\theta}_i^{(0)} - \hat{\theta}_{L_T}^{(0)}\right)} \right]^{1/T} \qquad (15)$$

A positive speed ($\hat{\lambda}_i > 0$) is consistent with the catching-up hypothesis while a negative speed reveals productivity divergence.

3. Empirical results

The sample used in this study consists of annual data for fourteen OECD countries : Australia (1), Belgium (2), Canada (3), Denmark (4), Finland (5), France (6), Germany (7), Italy (8), Japan (9), Netherlands (10), Norway (11), Sweden (12), United Kingdom (13), United States (14). The data span the 1970-2001 interval and were obtained from the International Sectoral Data Bank (ISDB) and the OECD STAN database for Industrial Analysis. It comprises value added expressed in international prices (base year 1990), labour input measured by total employment and capital stock, expressed in international prices (base year 1990). We focus on the total manufacturing sector.

3.1. Production frontier regression and TFP growth

The Time Varying Effect method consists in estimating Equation (9) and the two components of ε_{it} thanks to a one step generalised within procedure (cf. 2.2). The results of production frontier regression under constant returns to scale hypothesis are reported in Table 1.

Only seven out of the thirty six coefficients are non significant at the 5% confidence level. The output/input elasticities for labour and capital are respectively 0.83 and 0.17. Averages of TFP growth rates estimated with equation (12) for each country and for several country groups are presented in Table 2. On average, TFP growth rates are mainly explained by the common technical progress component (2.4%). The United States appears to be the leading country throughout the period and Finland has the highest growth rate of TFP with an efficiency change close to 1.7% per year. The euro-currency zone obtains the best progression of TFP and the highest relative efficiency levels.

Table 1: Production Frontier Regressions

	Estimated values of the coefficients					
Country *i*	$\alpha+\theta_i^{(0)}$	*(t-stat)*	$\gamma+\theta_i^{(1)}$	*(t-stat)*	$\theta_i^{(2)}$	*(t-stat)*
1	8.24E+00	*(19.07)*	1.95E-02	*(6.21)*	-5.40E-05	*(-0.62)*
2	7.99E+00	*(18.62)*	5.71E-02	*(16.13)*	-7.82E-04	*(-9.00)*
3	8.43E+00	*(19.20)*	4.25E-03	*(1.35)*	3.82E-04	*(4.29)*
4	8.03E+00	*(18.71)*	2.75E-02	*(8.73)*	-4.08E-04	*(-4.68)*
5	7.88E+00	*(17.86)*	1.45E-02	*(4.19)*	8.66E-04	*(9.75)*
6	8.38E+00	*(19.22)*	2.02E-02	*(6.10)*	1.25E-04	*(1.43)*
7	8.41E+00	*(19.51)*	2.13E-02	*(6.89)*	-1.99E-04	*(-2.27)*
8	7.95E+00	*(18.27)*	4.82E-02	*(15.06)*	-5.39E-04	*(-6.21)*
9	8.09E+00	*(19.73)*	3.64E-02	*(8.83)*	-3.47E-04	*(-3.75)*
10	8.27E+00	*(18.83)*	3.61E-02	*(10.55)*	-3.70E-04	*(-4.23)*
11	8.16E+00	*(18.80)*	6.65E-03	*(1.73)*	8.30E-05	*(0.86)*
12	8.15E+00	*(18.86)*	-2.88E-03	*(-0.98)*	1.06E-03	*(11.99)*
13	8.09E+00	*(19.17)*	1.63E-02	*(4.39)*	2.69E-04	*(2.91)*
14	8.73E+00	*(19.57)*	-5.10E-03	*(-1.59)*	9.50E-04	*(10.85)*
	Estimated values of the output/input elasticity					
$\bar{\beta}$	8.34E-01	(20.59)				

Table 2: TFP growth rates and Efficiency Levels

Country I and Zone	TFP	Efficiency Change	Technical Progress	Efficiency levels
AUS	1.78%	-0.66%	2.44%	66.64%
BEL	3.28%	0.85%	2.44%	70.16%
CAN	1.61%	-0.82%	2.44%	73.84%
DNK	1.49%	-0.95%	2.44%	55.58%
FIN	4.13%	1.70%	2.44%	53.82%
FRA	2.40%	-0.03%	2.44%	80.42%
WGR	1.51%	-0.92%	2.44%	78.57%
ITA	3.15%	0.71%	2.44%	63.59%
JPN	2.56%	0.12%	2.44%	66.31%
NLD	2.46%	0.03%	2.44%	79.08%
NOR	0.92%	-1.51%	2.44%	54.92%
SWE	3.00%	0.56%	2.44%	58.83%
GBR	2.46%	0.03%	2.44%	59.37%
USA	2.44%	0.00%	2.44%	100.00%
Euro zone	2.82 %	0.39%	2.44%	70.94%
European countries	2.48%	0.05%	2.44%	65.43%
Total OECD	2.37%	-0.07%	2.44%	66.24%

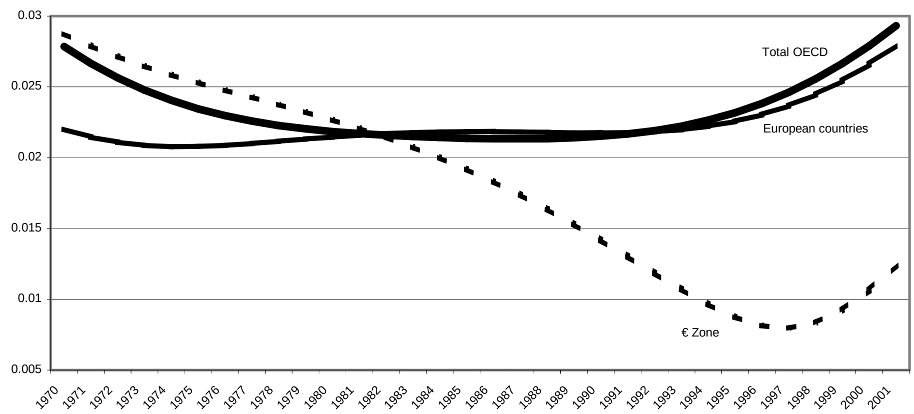
3.2. Technological catching-up

In order to evaluate the stability of the catching-up process over time and among countries, Figure 1 plots the coefficient of variation of Total Factor Productivity for three country groups: OECD, other European and euro-zone.

When considering only the first and the last year of the sample at hand, no significant phenomenon of catching-up to the leader (United-States) seems to appear. The standard deviation of TFP is even higher at the end of the sample than during the 70's. This result is fully consistent with the finding by Bernard and Jones (1996 a,b), Gouyette and Perelman (1997) and Hansson and Henrekson (1997) that there was no significant catching-up effect in the tradable sector.

However, Figure 1 also shows different patterns of the convergence process: the σ-convergence indictor decreases until 1986, and increases afterwards. This evolution shows that TFP levels converge towards their benchmark given by the performance of the American leader during the first seventeen years so that the catching-up hypothesis is supported over this sub-period. At the opposite, the TFP gap between the United-States and all other countries increases smoothly over the period 1986-2001. Notice that the patterns of the σ-convergence indicators are rather similar for the two first retained country groups, i.e. OECD countries and other European countries. Whereas a particular evolution is to be noted for the nations of the euro currency zone. The differentials of productivity between the latter nations strongly decrease until 1997 although since 1998, a phenomenon of divergence has reappeared without however finding standard deviations as high as those noted for the two previous groups.

Figure 1: Coefficient of variation of Total Factor Productivity (standard deviation/average, Levels of TFP in logarithm)



Due to the changing patterns in the catching-up process observed on Figure 1, the speed parameter is calculated with equation (15) for both the 1970-1986 and 1986-2001 sub-periods. As the United-States appears to be the leader over the whole period, the coefficients $\hat{\theta}_{L_t}^{(k)}$ in equation (15) are such that $\hat{\theta}_{L_t}^{(k)} = \hat{\theta}_{USA}^{(k)}$ $\forall k = 0,1,2$ and $\forall t = 0, T$.

Empirical results are reported in Table 3 and add support to the σ-convergence indicator analysis. During the period 1970-1986, a positive and significant speed is estimated for nearly all countries, suggesting that a catching-up process is at work and that technical diffusion takes place across countries over this period. The highest speeds are obtained for Belgium, The Netherlands and Italy. At the opposite, the estimated speed turns out to be negative and significant during the period 1986-2001, for all countries with the exception of Sweden and Finland. This result is also largely consistent with the pattern of the σ-convergence indicator over this period. The same results are obtained with average speed for both OECD, European and euro-zone country groups This evidence that TFP catching-up in the manufacturing sector was at work during the period 1970-1986 while TFP divergence occured during the period 1987-2001 is clearly at break with the finding by Bernard and Jones (1996 a) and Dowrick and Duc-Tho Nguyen (1989) that there is no catching-up effect in the manufacturing sector.

Decomposing the initial period and evaluating the catching-up by using a parametric stochastic production frontier permits to show that a catching-up reversal appears in the manufacturing sector in the midst 1980s. It is very difficult to provide any specific explanations as to why manufacturing industries have behaved so differently with respect to patterns of productivity catching-up. Growth slowed down in all countries during the 1970s and the dynamics of manufacturing productivity growth showed greater variation after 1979. Moreover while simple labour productivity indicators (such as value added per hour worked) reveal that all countries caught up with the USA in terms of labour productivity up to the midst 1970s, our TFP measure shows that the catching-up process worked until the mid 1980s.

Table 3: Average Speed of catching-up by period and by country (annual rate)

	1970–1986		1986–2001		1970–2001	
Pays	λ	t value	λ	t value	λ	t value
AUS	0.020	4.267	-0.043	-10.024	-0.011	-6.076
BEL	0.082	15.515	-0.054	-6.783	0.014	6.404
CAN	0.001	0.129	-0.042	-8.496	-0.020	-7.008
DNK	0.018	5.403	-0.041	-13.790	-0.011	-8.800
FIN	0.026	9.201	0.040	6.925	0.031	12.171
FRA	0.050	6.127	-0.053	-5.689	-0.001	-0.306
WGR	0.032	3.830	-0.077	-9.923	-0.021	-7.753
ITA	0.056	14.451	-0.033	-6.469	0.011	6.732
JPN	0.045	10.617	-0.041	-7.278	0.002	0.965
NLD	0.075	9.320	-0.078	-8.127	0.001	0.259
NOR	-0.004	-0.955	-0.036	-14.469	-0.020	-12.335
SWE	0.007	1.939	0.016	3.376	0.011	5.196
GBR	0.019	5.286	-0.017	-4.675	0.000	0.260
USA	Leader		Leader		Leader	
€ Zone (average)	0.053		-0.042		0.006	
European countries (average)	0.036		-0.033		0.002	
Total OECD (average)	0.033		-0.035		-0.001	

4. Conclusion

This paper has used an original testing procedure to re-examine the stability of the TFP catching-up hypothesis for the manufacturing sector across OECD, European and euro-zone countries over a period of thirty years. Empirical results suggest that contrary to previous conclusions put forth by authors such as Bernard and Jones (1996), Gouyette and Perelman (1997) and Hansson and Henrekson (1997), there was a significant movement towards TFP catching-up during the period 1970-1986 for OECD and European country groups. These catching-up patterns were reversed during the period 1987-2001. More homogenous productive efficiency profiles and better possibilities of technological adoption were established within the euro currency zone. Thus, TFP levels converged more quickly for the nations taking part in an economic and monetary union.

This result may indicate that while structural factors such as the capability to use the "best-practice technology" certainly constitute one of the main determinants of productivity growth, the characteristics of the technological catching-up process may be also dependent upon the institutional macroeconomic framework.

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