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**Working Paper**

## Alternative hypotheses of cross-country convergence: A non-parametric analysis of manufacturing sectors

Quaderni di Dipartimento - EPMQ, No. 196

**Provided in Cooperation with:**

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*Suggested Citation:* Dal Bianco, Silvia (2007) : Alternative hypotheses of cross-country convergence: A non-parametric analysis of manufacturing sectors, Quaderni di Dipartimento - EPMQ, No. 196, Università degli Studi di Pavia, Dipartimento di Economia Politica e Metodi Quantitativi (EPMQ), Pavia

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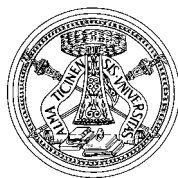
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## **Quaderni di Dipartimento**

**Alternative hypotheses of cross-country convergence.  
A non-parametric analysis of manufacturing sectors.**

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# 196 (04-07)

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Aprile 2007

Alternative hypotheses of cross-country  
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**April 2007**

**Abstract**

This paper examines labour productivity convergence tendencies, among 28 developed and developing countries, in manufacturing sectors, identified by production's technological content. An unified distribution dynamics framework is employed to test absolute and conditional convergence hypothesis, together with club convergence inner drivers, namely capital and technological initial conditions. The results provided are consistent with the hypothesis of club convergence in Resource Based, Low and Medium Technology sectors and with the hypothesis of absolute convergence in High Technology and Manufacturing as a whole. In particular, club convergence seems to be driven by technological initial conditions in Resource Based and Low Technology, while both capital and technology are determinant for Medium Technology overall convergence. This evidence shows that to catch-up with their richer counterparts, developing countries should enter R&D intense industries and target their industrial policy towards the development of dynamic advantages, such as knowledge and skills, rather than relying only on large production capacity, cheap labour and abundant natural resources.

*JEL Classification Code:* C14, O33, O47.

*Keywords:* Labour productivity convergence; distribution dynamics; stochastic kernel; ergodic distribution; technological transfer; manufacturing sectors.

# 1 Introduction

In the past fifty years, world income per capita has steadily increased at an annual average rate of 2,25%. Contemporaneously, world per capita income distribution has been characterised by two interesting features: first, the emergence of two distinct peaks, corresponding to poor and rich countries; and, second, the reduction of intra-distribution inequalities, that is a reduction in the spread between relatively poor and relatively rich economies (Durlauf and Quah (1999)).

This stylised evidence prompted a resurgence of interest in cross-country convergence. The point to be settled is whether or not developing countries are catching-up with their richer counterparts, in terms of income per capita or labour productivity.

In this work I study labour productivity convergence tendencies, among 28 developed and developing countries, in manufacturing sectors, identified by the technological content of their production according to Lall (2000) taxonomy. An original unified distribution dynamics framework is used to examine three alternative convergence hypotheses, namely: unconditional or absolute, conditional and club convergence. More precisely, understanding whether club convergence is mainly determined by capital or technological initial conditions (i.e. classical *vs* technological convergence) is one aim of the paper.

The results provided are consistent with the hypothesis of club convergence in Resource Based, Low and Medium Technology sectors and with the hypothesis of unconditional convergence in High Technology and Manufacturing as a whole. In particular, club convergence seems to be driven by technological initial conditions in Resource Based and Low Technology, while both capital and technology are determinant for Medium Technology overall convergence. Finally, labour productivity happens to unconditionally converge in both High Technology and total Manufacturing.

The focus on manufacturing compartments is motivated by the following considerations. First, since the seminal contribution of Lewis (1954), economic development has been associated with the process of industrialisation. Second, manufacturing is technologically the most dynamic sector in the world economy, in the sense that the greatest research efforts are made to launch new manufactures or to improve existing ones (Cornwall (1977)), United States Patent and Trade Mark Office, European and Japanese Patent Office, yearly data). Finally, thanks to outsourcing, industrial production is nowadays world integrated (UNIDO (2002); UNCTAD (2002)). This feature is crucial in convergence analysis because developed and developing countries interact with each others and their growth paths are interlinked. In particular, one specific dimension of cross-country interaction is explicitly considered here, that is technological transfer from the frontier economy to the others. As Pack and Westphal (1986) noticed, the innovation-imitation dynamics turns out to be the appropriate representation of technical progress when open economies, that have reached

different development stages, are considered.

Three are the features that render my study a significative contribution to the convergence literature, namely: sectoral disaggregation, sampled countries and distribution dynamics. Although a number of analysis have considered alternative hypotheses of convergence, taking into explicit consideration technological transfer, most of them have focused on aggregate GDP (Dowrick and Rogers(2002); Bianchi and Menegatti (2005)). Moreover, when different sectors' convergence tendencies have been analysed, only OECD countries got into the picture (Bernard and Jones(1996a) and Bernard and Jones(1996b); Scarpetta et al.(2000); Scarpetta and Tressel (2004)). Finally, all mentioned studies have employed parametric econometric techniques.

Distribution dynamics approach to convergence, which requires to estimate the law of motion of the entire cross-country labour productivity distribution, is preferred to traditional econometrics for the analysis of absolute and conditional convergence because, not relying in a definition of convergence as 'mean reversion process' (Quah(1993)), it allows to depict countries' relative economic performance; moreover, no sample split is necessary to test for club convergence (Durlauf and Johnson (1995); Desgoits (1999); Bloom et al. (2003); Graham and Temple (2003)).

To conclude, I want to stress a technical point of my analysis that improves established distribution dynamics methodology for calculation of long run distributions (i.e. ergodic distributions). This consists in computing the ergodic of distributions that have been conditioned to time varying (and likely endogenous) variables. Such a technique represents a step forward with respect to long run convergence analysis based on both discrete transition probability matrices (Quah (1996); Quah (1997); Epstein et al. (2003); Bandyopadhyay (2006)) and time invariant conditioning factors (Desmet and Fafchamps(2006)). The paper is organised as follows. In the second part, I define the alternative hypotheses of convergence taken into consideration and I present the variables and the data sources employed. The third section illustrates both the methodology used to estimate uncditioned transition probabilities and conditioning techniques. Details on empirical implementation are thorough the text. In the fourth, I present the fundamental tools for inferring convergence tendencies from distribution dynamics analysis and I discuss the results obtained. Relevant policy implications and possible lines for future research conclude.

## 2 Definitions and Data

In this section, I define the three hypotheses of convergence taken into consideration, namely: absolute or unconditional, conditional and club convergence. Moreover, I present the variables and the data sources used to test for labour productivity convergence in

manufacturing sectors, among 28 developed and developing countries.<sup>1</sup> Relevant data are collected from 1980 to 1995.

According to *absolute convergence* prediction, poor economies tend to grow faster than rich ones; then, contemporaneous per capita income differences are only transitory and will be null in the long run (Barro and Sala-i-Martin (1995)). *Conditional convergence* asserts that the long run equalisation of per capita income will arise only among countries that have identical structural characteristics (i.e. intertemporal preferences, development stage,...) (Barro(1991); Mankiw, Romer and Weil(1992)). Finally, when *club convergence* hypothesis is not rejected, it means that in the long run countries will converge only within small groups and not altogether. Holding this hypothesis, overall convergence comes up only if *both* countries' structural characteristics *and* initial conditions are evened out. (Azariadiz and Drazen (1990); Galor and Zeira(1993); Durlauf and Johnson (1995); Quah(1996); Quah(1997)).

My empirical analysis focuses on the evolution over time of log relative labour productivity distribution. The variable of interest is, then, labour productivity in country  $i$ , sector  $j$  at time  $t$ , relative to the one of United States, the leader economy (i.e.  $\log(Y_{ijt}/Y_{USjt})$ ).<sup>2</sup>

Normalising with respect to leader is a very convenient way of removing (some of) the trend from the cross-section (Quah(1996)). As noted in Desmet and Fafchamps(2006), working with detrended data is of particular importance to avoid degenerate long-run distributions. Further, it must be observed that this normalisation leaves unaltered how countries differ from each other but, obviously, requires to take United States out from the cross-sectional units under study. So, employing distribution dynamics, the behaviour of 27 countries' relative productivity will be analysed.

Labour productivity, in each country and sector, is measured as manufacturing value added per worker and it is denominated in 1996 international dollars.

Following Lall(2000) technological taxonomy, I identify the following manufacturing sectors: Resource Based (RB), Low Technology (LT), Medium Technology (MT) and High Technology (HT).<sup>3</sup>

Sectoral labour productivity data are expressed in 1996 international dollars to allow inter-

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<sup>1</sup>See Table 1 for sample details.

<sup>2</sup>United States represents the leader economy because this country has the highest labour productivity in all sectors, in the period considered.

<sup>3</sup>Lall(2000) taxonomy distinguishes manufacturing sectors according to research intensity, measured as Research and Development (R&D) expenditure share over sales' value. In particular, RB industries are the ones in which the values of production is essentially given by the possession of primary resources (e.g. processed food, manufactured tobacco, refined petroleum products); LT includes productions whose R&D expenditure is below 1% of sales' value (e.g. garments, footwear, pottery and cutlery); in MT R&D expenditure is between 1% and 4% of sales' value (e.g. automotive industry, agricultural machinery, perfumery and pesticides) and in HT R&D expenditure is greater than 4% of sales' value (e.g. electronics and scientific instruments).

national and intertemporal comparisons. They are obtained combining UNIDO Industrial Statistics Database 2004, at 3-digits of ISIC Code (Revision 2), World Bank Development Indicators and the latest version of Penn World Tables.<sup>4</sup>

To test for the hypothesis of labour productivity conditional convergence, following Quah(1996) I choose, as steady state proxies, the investment rates in both physical and human capital and a development dummy. In the empirical implementation, such variables, dummy apart, are taken in natural logarithms and normalised with respect to US values.

Sectoral investment rates in physical capital refer to Gross Fixed Capital Formation share to manufacturing value added. Both series are taken from UNIDO database.

To proxy human capital accumulation rate in each country, I use the average years of schooling in the population over age 15. This series comes from Barro and Lee(2000) dataset, which reports schooling variables only at five years interval. To overcome this difficulty, I interpolate the available data implicitly assuming that the between-observed values lie on a straight line.<sup>5</sup>

Developed countries represent the benchmark group of the dummy variable. Its values are determined following World Development Indicator classification.

I turn now to present the variables employed for the analysis of club convergence driving forces.

In checking whether labour productivity club convergence dynamics can be eventually ascribed to physical capital, I employ originally estimated sectoral capital stock series.<sup>6</sup> As before, such variable is taken with respect to United States and is expressed in natural logarithms.

To retrieve, instead, the relative strength of technological transfer for overall convergence, the technological variable is modeled following the conventional representation given by technological catch-up literature.<sup>7</sup> That is, Total Factor Productivity Gap (TFPgap) is taken to proxy the potential for technological imitation (Griffith et al.(2004)) and recipient economies' ability to assimilate and fruitfully exploit new knowledge (i.e. absorption

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<sup>4</sup>From UNIDO I collected disaggregated data on workers and on manufacturing value added in Local Currency Unit (LCU); from World Bank Development Indicators (WDI), GDP data in LCU; finally, from Penn World Tables (PWT 6.1), GDP data expressed in Purchasing Power Parity. After having calculated sectoral value added in manufacturing as percentages of GDP, using World Bank and UNIDO data in LCU, I combined such percentages figures with WDI and PWT6.1. My preferred measure of real value added in manufacturing is based on Penn World Tables Real GDP Chain Index (RGDPCH). This is because RGDPCH does not suffer from the so-called 'Laspeyres fixed-based problem' and, then, it is the most appropriate measure when intertemporal comparisons are at issue (Summers and Heston (1991)).

<sup>5</sup>My preference towards population over age 15, instead of 25, which is also available in Barro and Lee dataset, is motivated by the fact that working age in developing countries can be quite low. See for further details Bennell(1996).

<sup>6</sup>See for further details *Improving PIM to measure capital stock. Any implication for growth?* comprised in the present thesis.

<sup>7</sup>See for a complete review of the topic Rogers(2003).

capabilities) is considered as well.<sup>8</sup> In particular, I have used secondary school attainment rate, as absorption capability proxy.

TFPgap is expressed as the difference in technological levels between the leader and another country. Such variable is estimated employing the superlative index number approach introduced by Caves(1982a) and Caves et al.(1982b), using the previously mentioned data sources. By its very construction, it is already expressed in natural logarithms and no normalisation is needed.

From Barro and Lee(2000) dataset I take secondary schooling data. This choice is motivated on the basis of Gemmell(1996) results, which shows that for middle income countries, which are well represented in my sample, secondary education matters more than primary and tertiary ones. Also this series is taken in natural logarithms and normalised to United States.

### 3 Methodology

#### 3.1 Distribution dynamics and conditioning: non-technical summary

When distribution dynamics is employed, convergence tendencies among countries can be inferred analysing the evolution along time of cross-country labour productivity distribution.

Operatively, distribution's changes along time are retrieved using the stochastic kernel density estimator. In fact, this estimator allows to measure the probabilities of dynamic transitions from one labour productivity class to another, for each economy.

Two are the types of kernels employed in this paper:

1. unconditioned kernels
2. conditioned kernels

The unconditioned kernels give informations on the likelihood that an economy, starting from a given relative position in the initial period  $t$ , will end up improving or worsening its relative position in the final period  $t + s$ . In other words, it can be said that unconditioned kernels measure the transition probabilities from  $t$  to  $t + s$ .

Unconditioned kernels are used here to test the absolute convergence hypothesis.

Conditioned kernels are an extension of unconditioned ones. In particular, they allow to identify the factors that eventually lead club convergence dynamics. The effects of conditioning are identified by changes in shape and location of the kernel, with respect to the

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<sup>8</sup>Gerschenkron (1954) and Baumol (1986) provide the seminal contributions of the so-called 'capabilities approach' to economic development.



unconditioned case.

I will use conditioned kernels for testing both conditional convergence hypothesis and club convergence determinants.

In the case of conditional convergence, for example, if the unconditioned kernel shows twin peaks feature and, after conditioning with respect to steady state proxies, it is found that the conditioned kernel is single peaked, then, it can be said that club dynamics is lead by structural differences and that conditional converge hypothesis is not rejected.

### 3.2 Unconditioned transition probability estimates

In this section I provide a technical illustration of the methodology employed to estimate unconditioned transition probabilities, which are used to test the absolute convergence hypothesis.

Sectoral convergence tendencies are inferred analysing the dynamic behaviour of cross-country distribution of log relative labour productivity.<sup>9</sup>

Individual country  $i$  labour productivity, in sector  $j$ , at time  $t$  is called  $y_{it}$ , where I omitted the sector index for notational convenience (i.e.  $y_{it} = \log(Y_{ijt}/Y_{USjt})$ ). Cross country, sector specific, labour productivity distribution, at time  $t$ , is denoted as  $f_{Y_t}(y_t)$ , where  $Y_t$  indicates the corresponding random variable.

I assume that year-to-year changes in the distribution of labour productivity can be represented by an homogeneous Markow process, in such a way that,  $\forall t$ :

1.  $f_{Y_{t+1}|Y_t}(y_{t+1}|y_t) = f_{Y_{t+1}|Y_t}(y_{t+1}|y_t, y_{t-1}, y_{t-2}, \dots)$
2.  $f_{Y_{t+1}|Y_t}(y_{t+1}|y_t) = f_{Y_t|Y_{t-1}}(y_t|y_{t-1})$

The first property guarantees that only previous period income distribution impacts on next period one (i.e. history does not matter). The homogeneity assumption in 2 ensures that the transition probabilities do not vary with the time. Although quite restrictive, both hypotheses are necessary for estimating long run transition probabilities given the available data.

Conditional density functions,  $f_{Y_{t+1}|Y_t}(y_{t+1}|y_t)$ , represent the cornerstone of distribution dynamics convergence analysis. This kind of distribution, in fact, encodes informations about individual economies' passages over time. Thus, it sheds light on both intra-distribution dynamics and external shapes, making inference about convergence tendencies possible. For example, observing conditional density mappings, is it possible to know whether poor countries are catching-up with their richer counterparts, whether rich countries are still enriching, whether countries are converging overall or are clustering within

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<sup>9</sup>Please note that in what follows 'relative labour productivity' and 'labour productivity' are used interchangeably.

clubs.

The empirical estimation of conditional densities is handled by non-parametric techniques. To begin, it is worth to recall the definition of conditional distribution, that is the joint distribution divided by the marginal distribution. In formal terms:

$$f_{Y_{t+1}|Y_t}(y_{t+1}|y_t) = \frac{f_{Y_{t+1},Y_t}(y_{t+1},y_t)}{f_{Y_t}(y_t)} \quad (1)$$

The joint distribution of  $(Y_{t+1}, Y_t)$  can be estimated non parametrically using a bivariate stochastic kernel, while the marginal distribution of  $Y_t$  is obtained by numerical integration of the joint distribution. Finally, the conditional distribution is simply obtained by dividing one to the other, after appropriate discretization of the joint support.<sup>10</sup>

Long run tendencies towards convergence are encoded by the ergodic distribution. This is the stationary distribution of labour productivity, which will be approached in the long run should certain technical conditions hold.<sup>11</sup> In particular, if the ergodic distribution is unimodal and has a low variance, then long run cross-country convergence can be claimed. Formally, the ergodic is the distribution  $f$  which solves the following functional equation:

$$f(y_{t+1}) = \int_{-\infty}^{+\infty} f_{Y_{t+1}|Y_t}(y_{t+1}|y_t) f(y_t) dy \quad (2)$$

In order to compute the ergodic distribution the support of  $y$  is discretised in a set of  $N$  equally large intervals, where interval  $h$  is denoted as  $\Omega_h$ .<sup>12</sup>

Then, the probabilities of transition from one interval to another are calculated. Formally the probability of transition from the interval  $\Omega_h$  to another,  $\Omega_k$ , in one time period, is denoted as:

$$\alpha_{hk} = Pr(y_{t+1} \in \Omega_k | y_t \in \Omega_h)$$

At this point of the explanation, it is useful to adopt a compact matrix notation. Hence, the ergodic distribution is the vector  $p$  that solves the following system of equations:

$$p = Ap$$

$$(I - A)p = 0$$

where each component of the vector  $p$  represents the probability of  $y$  assuming a value comprised in a given  $\Omega$  and  $A$  is the matrix of transition probabilities  $\alpha_{hk}$ .

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<sup>10</sup>Bivariate stochastic kernel estimation is performed using the command *kdens2* in STATA 8.2. Marginal, conditional and ergodic distributions are calculated in Matlab. All programs are available from the author upon request.

<sup>11</sup>See Stockey, Lucas and Prescott (1989); Luenberger (1979).

<sup>12</sup>To avoid crude ergodic calculations, it is necessary to work with a sufficiently high  $N$ . My calculations have been done for  $N=50$ . Using  $N=200$  does not alter any conclusions but it has the disadvantage of slowing down computer's routines.

Since each column of matrix  $A$  is a marginal density and, then, its elements sum to 1;  $A$  does not have full rank and, by consequence, the system does not have a unique solution. To find a unique solution it is standard to simply drop one row of  $A$  (to make its columns linearly independent) and then add the restriction that the entries of vector  $p$  sum to 1.<sup>13</sup> Then, matrix  $A$  is rewritten as  $B$ :

$$B = \begin{pmatrix} 1 - \alpha_{11} & \dots & -\alpha_{1N} \\ \dots & 1 - \alpha_{ii} & \dots \\ -\alpha_{N-1,1} & \dots & -\alpha_{N-1,N} \\ 1 & \dots & 1 \end{pmatrix}$$

The modified system is then:

$$Bp = b$$

where the vector  $b$ , for the constraint added, has all entries equal to 0 except the last one, which is equal to 1.

At this point, the unique ergodic distribution,  $p$ , can be easily found inverting  $B$ :

$$p = B^{-1}b$$

### 3.3 Conditioning techniques

This part outlines the conditioning technique I used to test for conditional convergence and club convergence determinants.

Under the conditional convergence hypothesis, cross-country productivity equalisation can not be found in the original relative labour productivity distribution,  $f_Y$ , but in the conditioned one,  $f_{Y|X}$ , where  $X$  denotes steady state proxies. Then, the object of interest are the transition probabilities of the part of labour productivity not explained by the auxiliary variables (i.e. steady state proxies). Employing the former notation, such transition probabilities are formally written as:

$$f_{Y_{t+1}|Y_t, X_t}(y_{t+1}|y_t, x_t) \quad (3)$$

Exploiting Chamberlain(1984) results, the part of labour productivity orthogonal to auxiliary variables is computed as Ordinary Least Squares (OLS) residuals of the projection of labour productivity growth on each of the steady state proxies.<sup>14</sup> Such calculation involves three steps:

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<sup>13</sup>This constraint must hold for the definition of probability

<sup>14</sup>Quoting Quah(1996), Chamberlain(1984) finds that:

the projection of growth on investment, not allowing for individual effects, is precisely the best linear predictor and, thus, correctly gives residuals that are the components unexplained by (or, more correctly, orthogonal to) investment.

1. estimating the part of countries' relative productivity *growth rate explained* by conditioning steady state variables;
2. finding the *initial level* of relative labour productivity *explained* by conditioning steady state variables ;
3. combining the previous results to find the *level* of relative labour productivity *unexplained* by the auxiliary variables (i.e. orthogonal to steady state proxies).

Call  $g_{it}$  the growth rate of  $y_{it}$  (i.e. log relative productivity in country  $i$ , sector  $j$  at time  $t$ ), where again the sector index is omitted for notational convenience. Name  $\hat{g}_{it}$  the part of  $g_{it}$  explained steady state proxies, which are: investment rate in both physical and human capital, indicated as  $r_{it}$  and  $h_{it}$ , and the dummy development,  $ddev$ . Finally, the part of labour productivity orthogonal to steady state proxies, which is the object of interest, is called  $\hat{\epsilon}_{it}$ .

Step 1. is implemented regressing  $g_{it}$  on a two sided distributed lag of conditioning variables and saving the fitted values. For each steady state proxies one of such regressions is run. Then, cumulating the fitted values, by country and sector, the part of countries' relative productivity growth rate explained by conditioning steady state variables,  $\hat{g}_{it}$ , is obtained.

Note that in empirical work, multi-sided regressions are employed to handle endogeneity issues, which are represented in this specific case by the likely bidirectional causality between labour productivity growth rate and steady state proxies. This technique, introduced by Sims (1972), has been extensively used by Quah, who noticed that just 2 leads and 2 lags are sufficient to clear the estimated growth rate from feedback effects (Quah(1996)).

Step 2. is taken running a pooled OLS regression of  $y_{it}$  on time averages of steady state proxies (i.e.  $\overline{r_{it}}$  and  $\overline{h_{it}}$ ) and the estimated growth rate (i.e.  $\hat{g}_{it}$ ). For each sector, the coefficients that solves the following minimisation problem are used to pin down the initial level of labour productivity explained by steady state variables,  $\hat{y}_{i0}$ :<sup>15</sup>

$$\min_{\beta_1, \beta_2, \beta_3} \sum_i \sum_t [y_{it} - (\beta_1 \overline{r_{it}} + \beta_2 \overline{h_{it}} + \beta_3 ddev + \hat{g}_{it})]^2$$

In fact, thanks to the estimated coefficients,  $\hat{\beta}s$ , the initial level of log relative labour productivity explained by conditioning variables can be expressed as:

$$\hat{y}_{i0} = \hat{\beta}_1 \overline{r_{it}} + \hat{\beta}_2 \overline{h_{it}} + \hat{\beta}_3 ddev$$

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<sup>15</sup>As Quah(1996) explains, this technique exploits the cross section variation of conditioning variables to compute the initial value of productivity explained steady state proxies.

Then, adding the growth rates of step 1, the level of relative labour productivity explained by steady state variable is calculated as:

$$\hat{y}_{it} = \hat{y}_{i0} + \hat{g}_{it}$$

Finally,  $\epsilon_{it}$ , which represents the productivity level not accounted for (or conditional to) steady state proxies is simply found subtracting from actual the estimated relative labour productivity:

$$\hat{\epsilon}_{it} = y_{it} - \hat{y}_{it}$$

Once country and sector specific  $\epsilon_{it}$  series have been calculated, the empirical implementation for testing conditional convergence is the same as absolute (or unconditional) convergence.

In particular, bivariate stochastic kernel densities fit cross-country, sector specific, distribution of relative productivity orthogonal to steady state variables, which I denote as  $f_{\hat{E}_{t+1}, \hat{E}_t}(\hat{\epsilon}_{t+1}, \hat{\epsilon}_t)$ . By numerical integration of the joint distribution, the marginal density  $f_{\hat{E}_t}(\hat{\epsilon}_t)$  is obtained. Finally, the transition probabilities of Equation(3) are found dividing the joint distribution,  $f_{\hat{E}_{t+1}, \hat{E}_t}(\hat{\epsilon}_{t+1}, \hat{\epsilon}_t)$ , by the marginal distribution,  $f_{\hat{E}_t}(\hat{\epsilon}_t)$ .

Long-run distribution of relative labour productivity conditioned to steady state variables is retrieved from the ergodic distribution of random variable  $\hat{\epsilon}_t$ . Such a distribution is calculated as for the unconditional case (previous section).

Turning now to club convergence analysis, it should be intuitive that the conditioning scheme described so far can be easily extended to determine the relative strenght of club convergence inner drivers.

In particular, when club convergence hypothesis holds, the object of interest becomes the dynamics of labour productivity distribution conditioned to both steady state proxies and club convergence driving forces, namely capital and technological initial conditions. Formally, the following transition probabilities has to be computed:

$$f_{Y_{t+1}|Y_t, X_t, Z_t}(y_{t+1}|y_t, x_t, z_t) \quad (4)$$

where the variable  $Z$  represents either initial capital stock or initial technological level, which has been proxied by TFPgap and school attainment rate.

To retrieve the relative strength of capital stock (or technology) as club convergence determinant, relative labour productivity orthogonal to both steady state proxies and capital stock (or technology) initial level must be calculated. This is done implementing the three steps previously described, taking into consideration capital stock (or technology) as extra conditioning variable.

By the same tokens as before, the density in Equation (4) and the ergodic distributions are computed.

To conclude, it is worth noticing that the conditioning scheme I employed allows not only

to work out alternative convergence hypotheses within a unified framework but also to calculate the ergodic of distributions that have been conditioned to time varying (and likely endogenous) variables. This latter aspect is particularly worth because it represents a step forward with respect to long run convergence analysis based on both discrete transition probability matrices (Quah (1996); Quah (1997); Epstein et al. (2003); Bandyopadhyay (2006)) and time invariant conditioning factors (Desmet and Fafchamps(2006)).

## 4 Results

### 4.1 Interpreting results

I now provide the fundamental tools for inferring convergence tendencies from the graphs that constitute the results of my analysis. Such diagrams, mapping the transition probabilities of different types of distribution (i.e. unconditional, conditional to steady state proxies, etc), allow to test for alternative hypotheses of convergence.

Figures like 1.1.1 and 1.1.2 describe eight year horizon distributions' evolution and are used to establish medium run tendencies to convergence.<sup>16</sup> More precisely, the first type of graphs shows a tridimensional plot of transition probabilities, estimated by stochastic kernels; the second type, mapping the level curves, represents the stochastic kernels in just two dimensions. In both diagrams, the floor axis, marked as Period  $t$  and Period  $t + 8$ , measure the log of relative productivity in different times.<sup>17</sup>

*Convergence* tendencies, in the medium run, can be claimed if the kernel rotates clockwise and accumulates on a single ridge parallel to Period  $t$  axis. That is, relative productivity levels become equal across countries, regardless of economies' initial position. *Persistence* is found when the mass concentrates along the 45 degrees line. So, countries' initial and the final positions coincide. *Improvements*, with respect to the initial position, are detected if the mass piles above the 45 degrees line; by the same token, *worsening* occur when the mass lies below the diagonal. *Club convergence* is signalled by distinct peaks along the diagonal.

As explained in the methodological section, long run tendencies, should the current dynamics persist, are assessed through ergodic distributions, like Figure 1.1.3. The shape the ergodic is likely to have can be anticipated by mobility analysis. Mobility analysis, in fact, values whether countries will change their relative position over time or not. An example can easily clarify this point.

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<sup>16</sup>I also calculated transitions over one year horizon. Although the results do not change significantly, over such a shorter period, mobility is slightly lower and emerging patterns seem more difficult to trace.

<sup>17</sup>To make graph interpretation easier, in Table 2 I explicitly express Period  $t$  and Period  $t + 8$  values, in % terms with respect to the leader.

Take the contour plot of Resource Based Unconditioned stochastic kernel. It can be seen that there are three groups of economies, signalled by red and yellow circles. Call them: poorest, poor and rich. Pick the poorest, with values comprised by -4.2 and -3.5 in period  $t$ , and ask: where will these countries end up in the next eight years? -3.5 is the answer. Then, ask again: what will happen to the same economies in the following eight years, should the current tendencies persist? The most likely outcomes are either remaining around -3.5 or improving until a maximum of -1.75. Thus, some of the poorest will be trapped around -3.5, while some others will get relatively better. In the latter case, ending in -2.5 seems very probable. From this value, further improvements are likely at least until -1.5, which represents the long run productivity value for some former poorest and poor economies.<sup>18</sup> For higher values than -1.5 (i.e. rich economies), the distribution has a peak centered around -1. This is a convergence club sign. In fact, along time, some rich economies will converge to -1 from below and others from above. The mobility analysis, then, predicts an ergodic with three peaks. Such a prevision is confirmed by Figure 1.1.3. I turn now to the interpretation of long run convergence tendencies.

In general terms, it can be said that any alternative convergence hypothesis is not rejected when the correspondent ergodic distribution is unimodal and has a low variance.

In the case of unconditional convergence, a single peaked ergodic means that labour productivity will be equalised among all countries, no matter their difference in structural characteristics or initial conditions.

When unconditional convergence is rejected, conditional convergence is tested. If its ergodic turns out to be unimodal, then countries' peculiar structural characteristics are responsible of unconditional convergence lack. If, on the other hand, the ergodic has more than one peak, smoothening out steady state dissimilarities does not remove the dynamics of clustering into clubs.

Finally, the analysis of club convergence determinants is carried out equalising both countries' structural characteristics and initial conditions. In particular, capital stock is marked as club convergence driving force when the ergodic distribution, conditioned with respect to steady state proxies and capital stock, is unimodal. The same reasoning applies for establishing that club convergence originates from an ineffective process of technological transfer, that can be due to either insufficient imitative potential (i.e. TFPgap) or lack of absorption capabilities (i.e. secondary school attainment rate).

## 4.2 Discussing results

My results are presented by technological sector. I begin their illustration from the description of three stylised features, supported by the study of unconditional and conditional

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<sup>18</sup>To see why initially poor economies should end here, just pick them, instead of poorest, at the beginning of the exercise.

convergence.

The first interesting point is that productivity differences among countries tend to be smoothened over time. From unconditional contour plots (i.e. absolute convergence), in fact, it can be seen that poor countries are likely to improve their relative position (i.e. mass piled above the 45 degrees line), while rich are more likely to get worse (i.e. mass below the same diagonal).

The second thing to notice is that, when steady states differences are taken into account (i.e. conditional convergence's kernels), some countries overtake the leader (i.e. log relative productivity greater than zero) and the location of overall distribution shifts towards higher values. This finding, robust in applied literature employing distribution dynamics (Quah(1996), Bandyopadhyay (2006)), shows that conditioning variables affect the behaviour of productivity in each country. The explanation provided by theoretical models on technology diffusion is that some laggards countries might eventually do better than the leader, in terms of productivity level, because they are able to fast imitate leader's innovations (Barro and Sala-i-Martin (1997)).

However, and here the third stylised feature arises, no sector exhibits conditional convergence dynamics. Hence, structural characteristics influence each country relative productivity without affecting the dynamics of the entire distribution, which is still characterised by club convergence tendencies (Quah(1996)).

I now turn to sectoral analysis, starting from Resource Based and Low Technology. All alternative convergence hypotheses will be discussed.

Looking at unconditional convergence, RB and LT productivity distributions exhibit three distinct peaks. Contour plots show that the highest one in RB and the middle one in LT, in correspondence of -0.9 and -1.9 respectively (i.e labour productivity is 40% and 15% of leader's), are centered along the 45 degrees line. Thus, they can be expected to be convergence basin, that is productivity levels towards which countries are likely to converge in the long run. For what concerns the other peaks, probability mass around the lowest in RB is predominantly above the main diagonal, so few poor countries should be trapped at low productivity levels. Moreover, if any low productivity basin has to originate, it will be in correspondence of -3.5 (i.e. 3% of leader's labour productivity), where the 45 degrees line cuts such a peak. Countries in the middle part of RB distribution will converge towards -1.4 (25% of leader), most likely from below (i.e. initial productivity levels lower than -1.4). Very similar analysis, can be carried for LT, where two or three convergence basins can be expected, depending on the probability of lowest productivity countries to stay put. The ergodic distributions confirm such intuitions: three convergence clubs in RB, where the lowest club is barely probable; and two in LT. In conclusion, the unconditional convergence hypothesis is rejected in both sectors.

Passing to conditional convergence and looking to contour plots, the tendency for poor to



get richer and rich poorer is evident for both RB and LT. Although, by the same tokens as before, some convergence basins seem to arise and, looking to the ergodics, three clubs will be formed in the long run in RB and two in LT. Hence, also the conditional convergence hypothesis has to be rejected. As discussed before, this means that the equalisation of structural characteristics alone can not change the law of motion of the entire distribution, whose peculiarity is represented by club convergence dynamics.

Finally, I test for club convergence determinants. Starting from RB, the comparison of Figures 1.3.3 and 1.4.3 shows that technological differences are the main club convergence determinants. This means that dissimilar technological initial conditions among countries (i.e. developing countries' technological lack) are preventing from overall (conditional) convergence. In this case, in fact, the ergodic distribution is single peaked and quite concentrated around -0.6, which corresponds to 55% leader's productivity. On the other hand, if countries had similar structural characteristics and initial capital stock, the ergodic would be highly dispersed and multi peaked. The same conclusion can be drawn for LT sectors. In particular, from Figure 2.4.3 can be inferred that all countries will converge in the long run towards a productivity level equal to 37% of leader's in LT.

My first result then is that, in RB and LT sectors, countries would converge overall only if they were similar in terms of structural characteristics and technological initial conditions. For how I constructed the technological proxy, developing countries' technological lack can be either due to missing imitative potential or insufficient absorption capabilities, or both. Although it is very difficult to measure which technology is relevant for specific sectors, a rough idea of potentially transferable technology can be provided considering the focal activities of Multinational Corporations (Dunning (1993); Lall (2001)). In the past 30 years, top 30 world Multinational Corporations (MNCs) has been investing in High Technology sectors (UNCTAD (2004)). Thus, the sectoral pace of developed countries' investment might have lowered the potential for technological upgrading in traditional sectors, which account for an average 77% of laggards economies' manufacturing value added. To refine the picture, it must be also considered that top 50 developing countries's MNCs, 33 of whom from South East Asia, operate in LT and service sectors (UNCTAD (2005)). Thus, the bimodality of Figure 2.3.3 might be explained considering that technological spread in such compartment has been headed by firms that eventually have lower standards than international ones (Lall (2001)). Finally, the possibility of insufficient learning ability or incentives to implement new technologies has to be taken into account, considering the increasing mechanisation that RB and LT productions have experienced in the last fifty years (UNCTAD (2005)).

I turn now to Medium Technology sectors.

The unconditional convergence hypothesis can be rejected on the basis of Figures 3.1.2 and 3.1.3. From the ergodic, in particular, it could be easily seen that some few countries

will be trapped within a low productivity basin. Although a general tendency towards equalisation can be inferred from the contour plot, conditional convergence can not be accepted neither. The ergodic, in Figure 3.2.3 is quite dispersed and exhibits two peaks, one in correspondence of -1.1 (33% of leaders') and the other in -0.75 (47%). (nota: Please note that the dimension of contour plot's and ergodic's boxes are different, in particular contour plot is 93% of ergodic. To infer the numbers reported in the text I have made their scales comparable). Then, this evidence is consistent with the club convergence hypothesis.

The strength of capital accumulation and technological transfer, as club convergence inner drivers, is tested, respectively, in Figures 3.3.1 to 3.3.3 and in Figures 3.4.1 to 3.4.3. From contour plots, two convergence clubs can be expected in both cases; one in correspondence of low relative productivity, between -2.5 and -2, and one in between of -1 and -0.5. The ergodics, in pictures 3.3.3 and 3.4.3, in fact, exhibit twin peaks feature. More in detail, when capital stock differences are evened out, the majority of the countries cluster around a productivity level of 60% of the leader, and only few of them will be stucked at 13% of US productivity. On the other hand, when technological initial conditions are taken into account, it is more likely to reach a productivity level of 8% than of 34%. In sum, equalising capital initial conditions might make the countries better off overall. Although this difference, the bottom line of the analysis is that neither capital or technological differences alone can account for club convergence dynamics.

Such a result can be interpreted in the light of MT peculiar features. These sectors have both complex technical requirements and demand for large scale production. Thus, to fill the productivity gap developing countries have to properly develop both dynamic advantage (i.e. technology and skill) and to strengthen factor markets (i.e. credit and finance), coping with domestic market failures (Lall (1992)).

I pass to discuss now HT sectors behaviour.

My analysis supports the absolute convergence hypothesis. That is, in the long run countries will converge to the same productivity level, regardless their structural and initial conditions. From Figure 4.1.2, it is evident that poorest countries are very likely to improve their relative position while richer will either stagnate around -1 (37% of US labour productivity) or will converge close to that level from above. In fact, the ergodic is single peaked around 47% of leader's productivity.<sup>19</sup>

Unconditional convergence in HT sounds surprising because, due to the high technological content of such productions, technical and capital deficiencies in developing countries have

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<sup>19</sup>To confirm the robustness of unconditional convergence prediction, I have used as counterfactual HT labour productivity distribution conditioned to both steady state proxies and capital plus technological initial conditions. The ergodic of this distribution has more than one peak and it is highly dispersed. Thus, unconditional convergence is validated. To save space I did not report such analysis, which is available upon request.

been expected.

From an optimistic perspective, absolute convergence result could be interpreted considering that foreign capital inflows, together with domestic industrial policies targeted towards HT, have provided good initial conditions and have effectively rescued laggard economies from domestic market failures, then naturally equalising structural differences.

However, the picture might get less encouraging. First of all, my result seems to contradict the one in Scarpetta and Tressel(2004). Employing standard parametric techniques they find that Total Factor Productivity (i.e. technological proxy) convergence among OECD countries is weaker in High Tech industries than traditional sectors. Secondly, much of HT production is currently set up by developed countries' firms outsourcing strategies (UNCTAD (2005), UNIDO (2005)). Thus, developing countries might act just as outdoor plants, assembling foreign intermediates, while high valued operations stay put in developed world (UNCTAD (2005); Singh (2006)). With this respect, it could be useful to reconsider the results I obtained for RB and LT sectors. If, in fact, developing countries were autonomously able to close the productivity gap in knowledge intense sectors, why they would not do the same in traditional productions? The technological lack found in RB and LT, which are mainly constituted of indigenous firms (UNCTAD (2003)), could signal at least the absence of knowledge spillovers from HT sector. Pushing things to extreme, it could be the case that indigenous technological knowledge in HT does not spill over other sectors because there is no indigenous technological knowledge. Thirdly, there could be a sample selection problem, in the sense that developing countries of my analysis, that are the ones for which disaggregated manufacturing data are available and reliable, might be particularly productive in HT industries (Lall (1997)).

In conclusion, absolute convergence finding in HT calls for caution and moderate optimism.

To terminate the discussion of my results, I analyse convergence tendencies in Manufacturing sector as a whole.

As in HT, also in this case the unconditional convergence hypothesis can not be rejected. This result is consistent with the findings of Scarpetta et al.(2000), Bernard and Jones(1996a) and Broadberry(1993). In particular, from contour plot in Figure 5.1.2, the general tendency of poor becoming richer and rich poorer can be retrieved. The ergodic shows that, in the long run, countries will converge overall around half of US labour productivity.

My analysis, as the one of Scarpetta and Tressel(2004) and Scarpetta et al.(2000), shows that converging tendencies in whole manufacturing are different from the ones prevailing in specific subsectors. Then, interesting dynamics can be masked if the industrial sector is considered only as aggregate.

Furthermore, it might be claimed that the similarity between HT and TOT patterns are

due to the fact technology intense compartments are leading the whole industrial performance. In my opinion, this kind of reasoning can not be taken as granted. On one hand, if it is true that HT has grown faster than all other sectors (i.e. 8% vs 4% on average. UNIDO (2002)); on the other, HT weight over total manufacturing production accounts just for an average 12%.

## 5 Conclusions

This paper outlines the salient features of labour productivity convergence in manufacturing sectors, among 28 developed and developing countries.

My empirical analysis, grounded on distribution dynamics, is consistent with the hypothesis of club convergence in Resource Based, Low and Medium Technology sectors and with the hypothesis of unconditional convergence in High Technology and Manufacturing as a whole. In particular, club convergence seems to be lead by technological initial conditions in Resource Based and Low Technology, while both capital and technology play a part in Medium Technology clustering tendencies. Finally, labour productivity happens to unconditionally converge towards half of US' level in both High Technology and total Manufacturing.

Sector specific policy implications are drawn from my results.

For what concerns traditional industrial sectors (i.e. RB and LT), it could be said that developing countries will converge towards developed economies labour productivity levels only if they would be able to close their technological gap. This process requires both to have access to relevant frontier technology and to be able to assimilate, and fruitfully exploit, new knowledge. Thus, in the actual context of world integrated production, developing countries' industrial policy should be targeted in the direction of technology attainment and of domestic capabilities building. This means, on one hand, that any form of technological transfer (i.e. FDI, licensing, subcontracting,...) should be channeled and improved and, on the other, that institutional infrastructure for learning and creating new technical skills should be provided.

Regarding MT sectors, both technological delay and underinvestment issues have to be faced by laggard economies. Thus, together with the policy recommendations already formulated for RB and LT, it might be said that developing countries have to strengthen credit and financial markets to catch-up with their richer counterparts.

Some caution is needed to evaluate the result I obtained for HT sectors. In my opinion, conclusive policy recommendations call for additional analysis. In particular, two more steps should be taken. First, convergence tendencies among developing countries alone need to be tested, to face the sample selection problem mentioned in the previous para-

graph. Such an exercise, in fact, might shed some light on whether laggard economies are following a common development path in knowledge intense industries or not. Actually, recent descriptive literature have found that developing countries industrial performances in HT has been increasingly divergent since the late 80s (Lall (2001) UNCTAD (2002); UNIDO (2002)). Second, it could be useful to consider not only developing countries innovative activities (i.e. technological transfer and imitation) but also developed countries' R&D efforts, which might be expected to be significative in knowledge intense industries. Although very interesting and convenient, this lines of research are quite difficult to pursue. The main difficulty being data lack on, respectively, low income and least developed countries industrial performance in HT and sectoral R&D data.

Finally, observing the convergence tendencies in whole Manufacturing, which constitute a quite well established result in the literature, it could be interesting, especially from the policy perspective, to contrast such a convergence result with the dynamics of other economic sectors, services in particular.

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<b>Developed OECD</b>	<b>Developed NON OECD</b>	<b>Developing Middle Income</b>	<b>Developing Low Income</b>
Australia	Cyprus	Bolivia	Bangladesh
Austria	Hong-Kong	Chile	India
Finland	Israel	Egypt	
Greece	Singapore	Indonesia	
Italy		Iran	
Japan		Jordan	
Korea		Malaysia	
Norway		Philippines	
Spain		Sri Lanka	
United Kingdom		Turkey	
United States		Venezuela	

Table 1: Country Sample

Logarithmic scale $y_{ijt} = \log\left(\frac{Y_{ijt}}{\bar{Y}_{USjt}}\right)$	Labour productivity in % with respect to US
-4	2%
-3.5	3%
-3	5%
-2.5	8%
-2	13%
-1.5	22%
-1	37%
-0.5	60%
0	<b>100%</b>
0.5	164%
1	271%
1.5	448%

Table 2: Graphs Scale

## Resource Based

### Absolute convergence

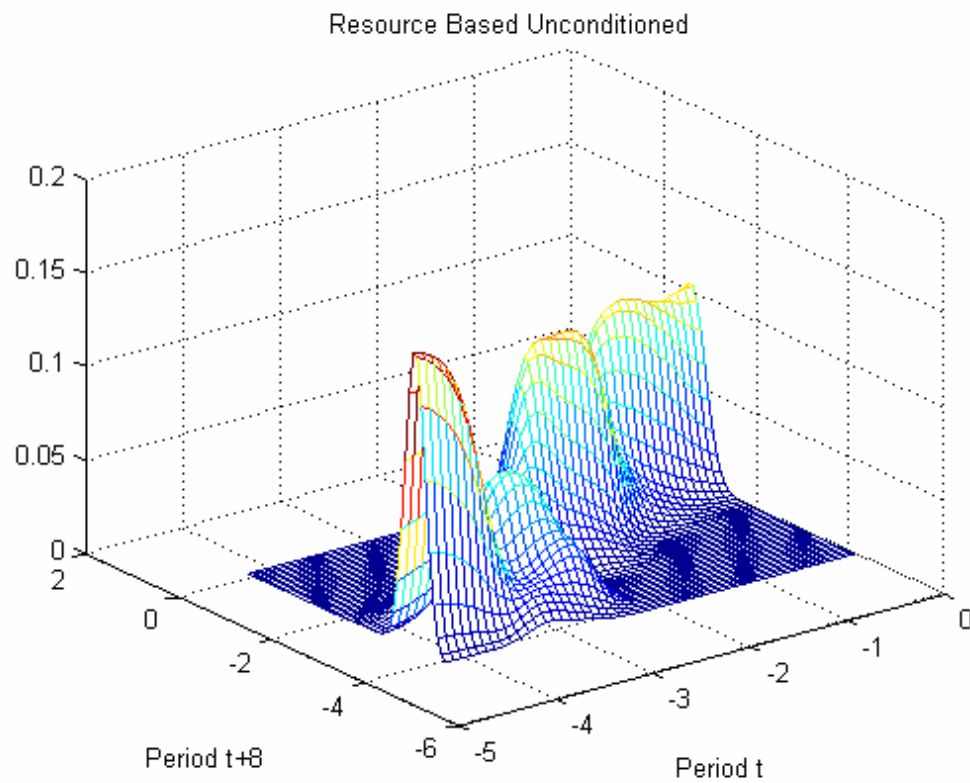


Figure 1.1.1.

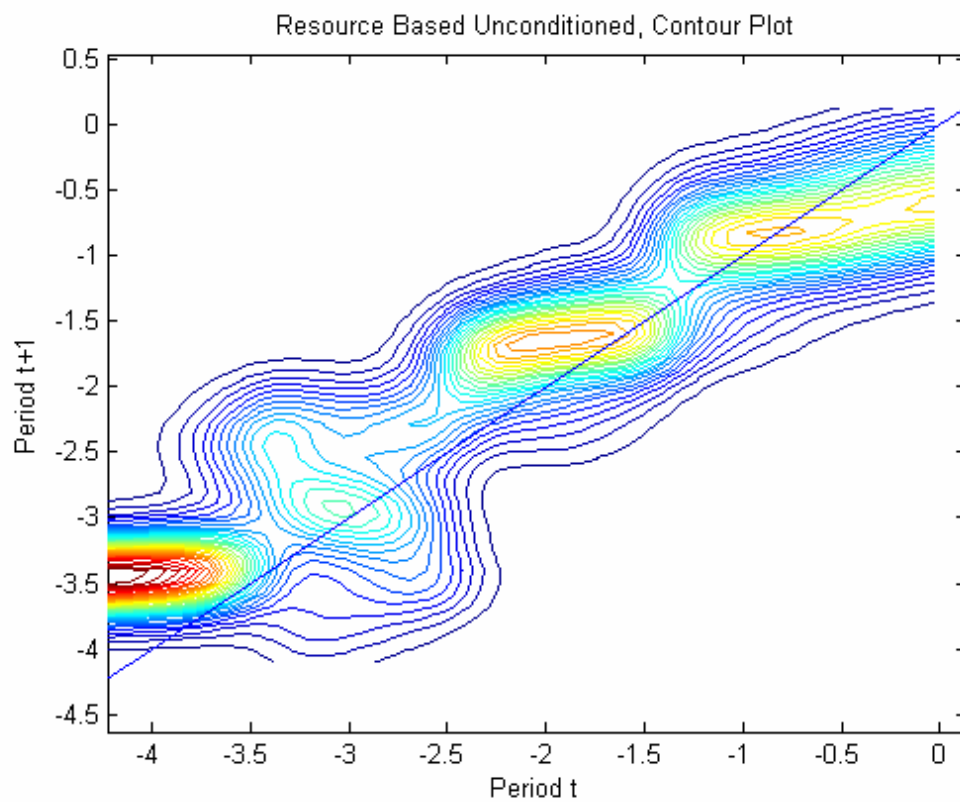
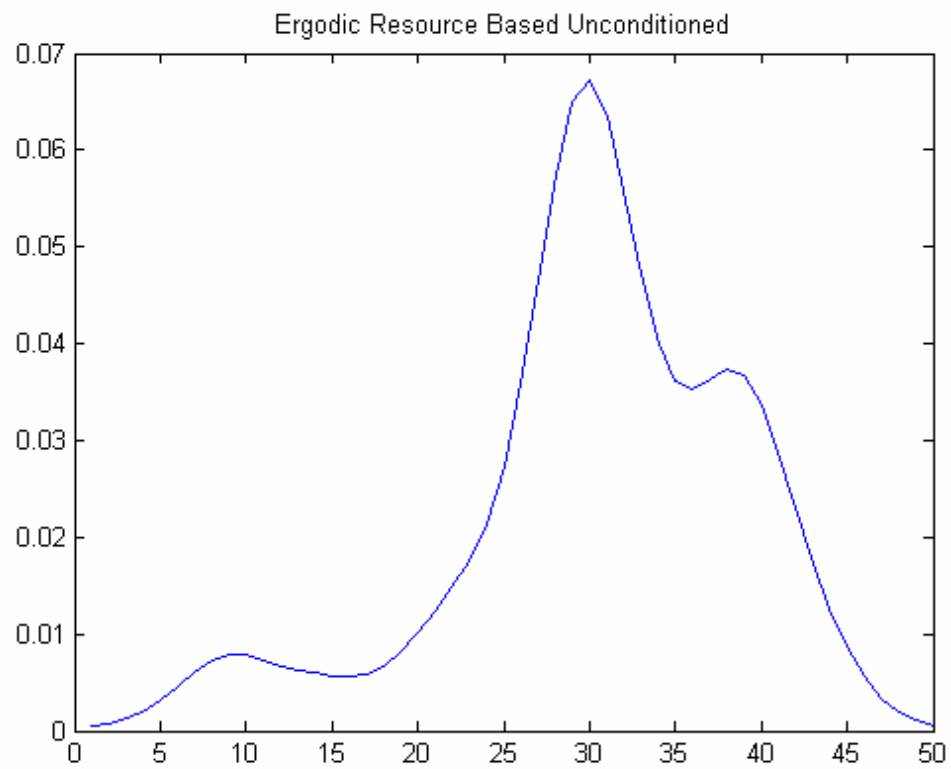
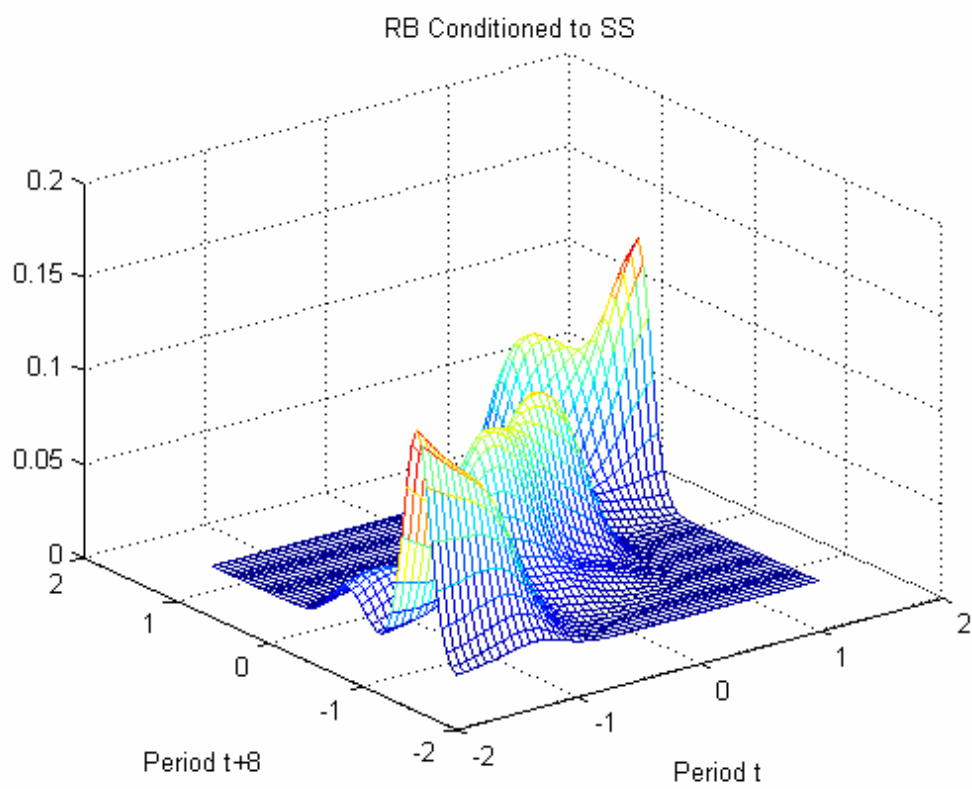


Figure 1.1.2.

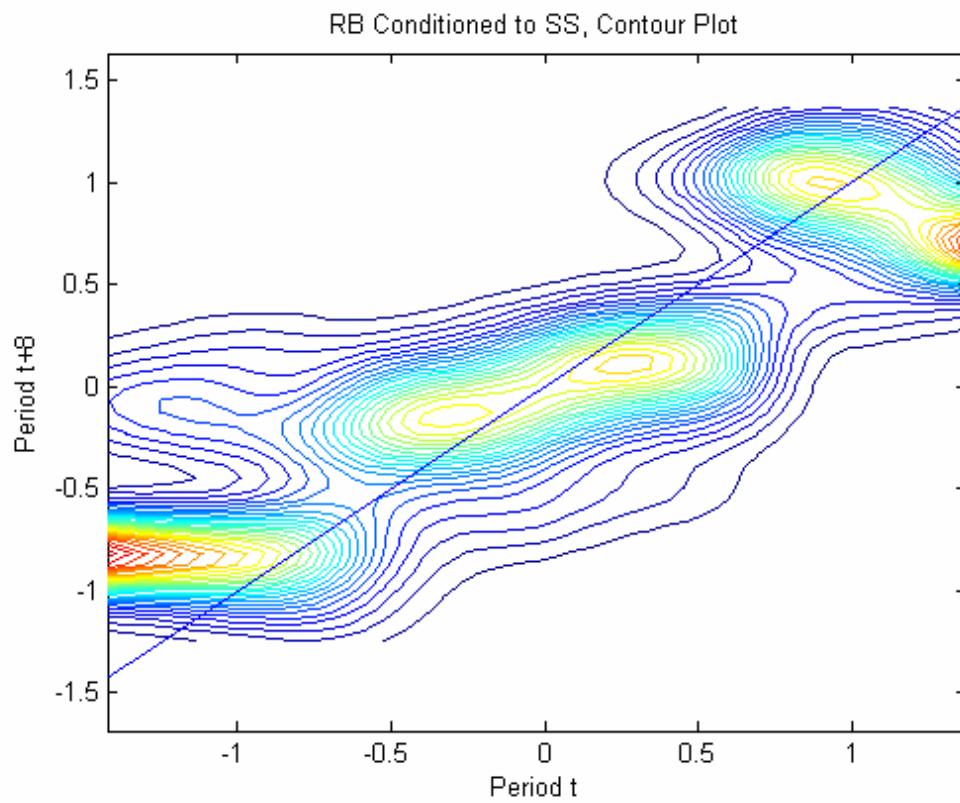


**Figure 1.1.3.**

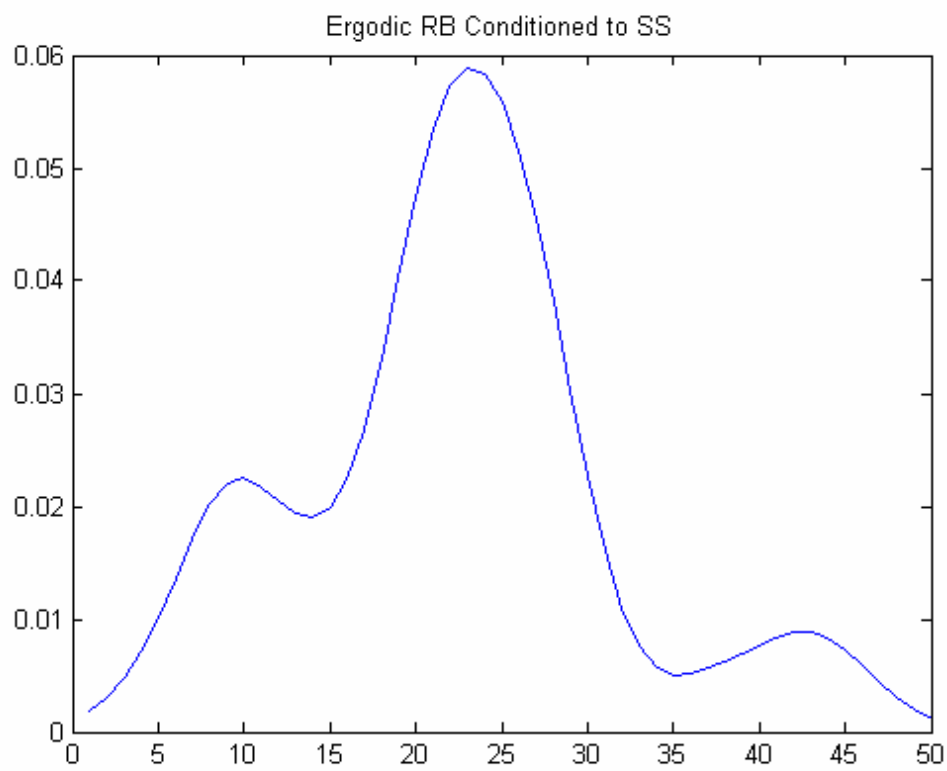
### Conditional convergence



**Figure 1.2.1.**



**Figure 1.2.2.**



**Figure 1.2.3.**

### Capital stock initial conditions as club convergence inner driver

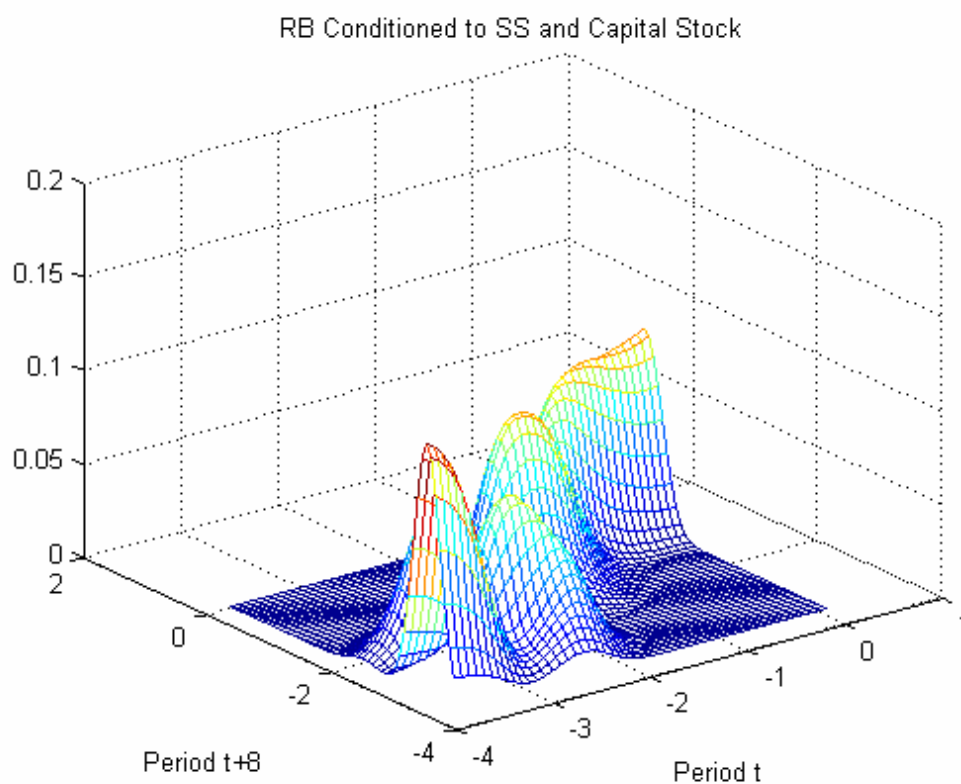


Figure 1.3.1.

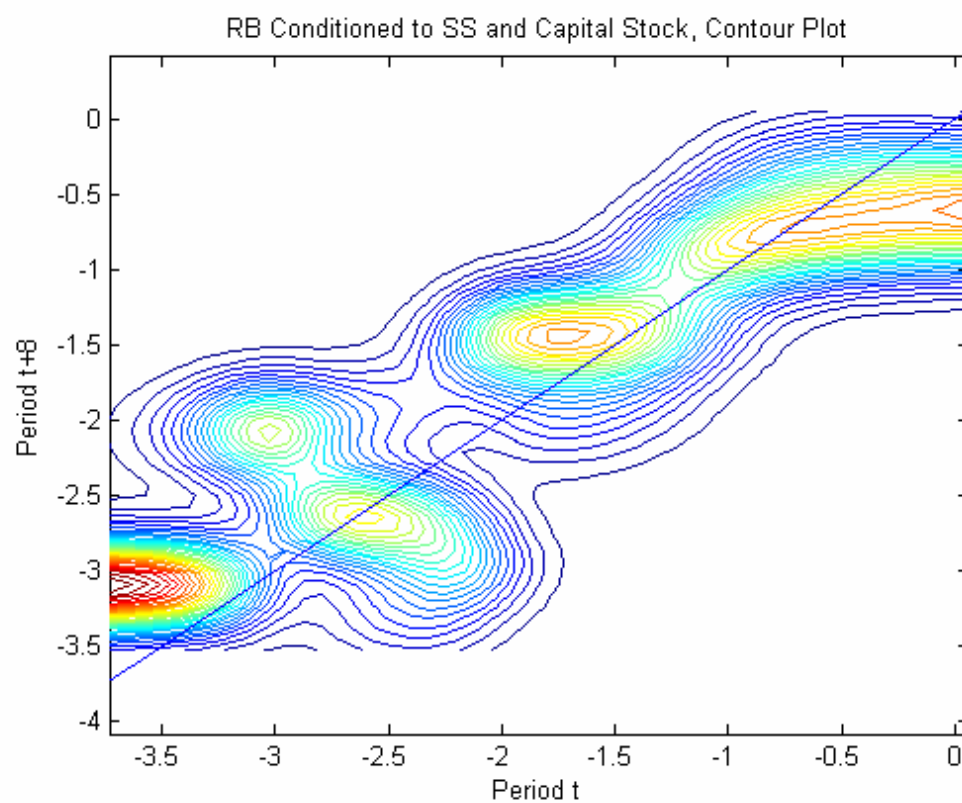


Figure 1.3.2.

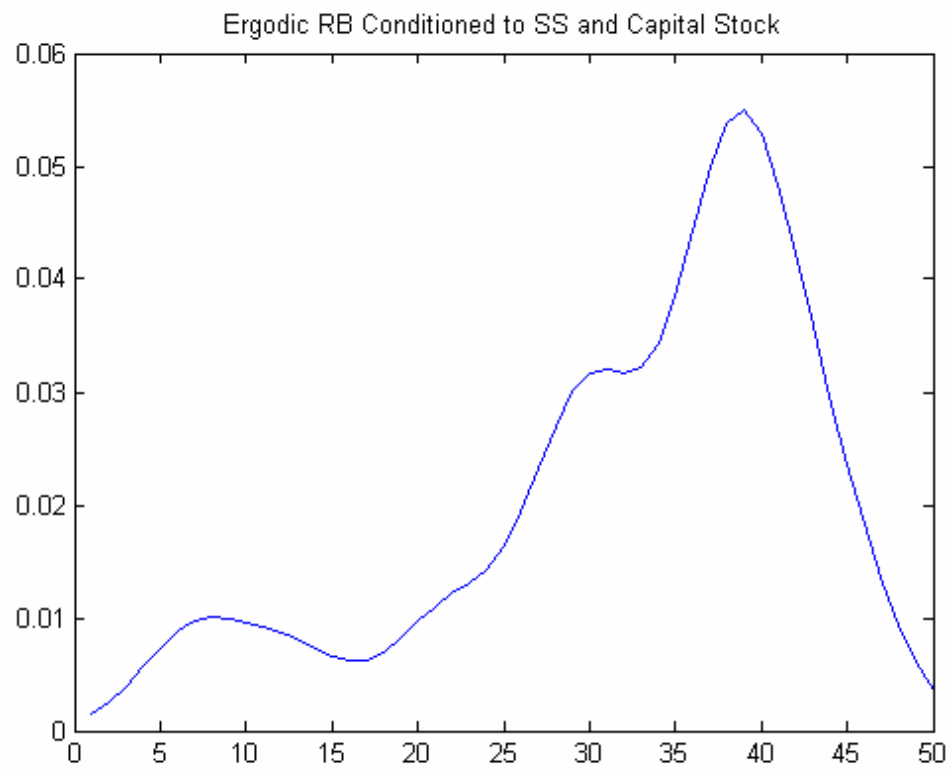


Figure 1.3.3.

### Technological initial conditions as club convergence inner driver

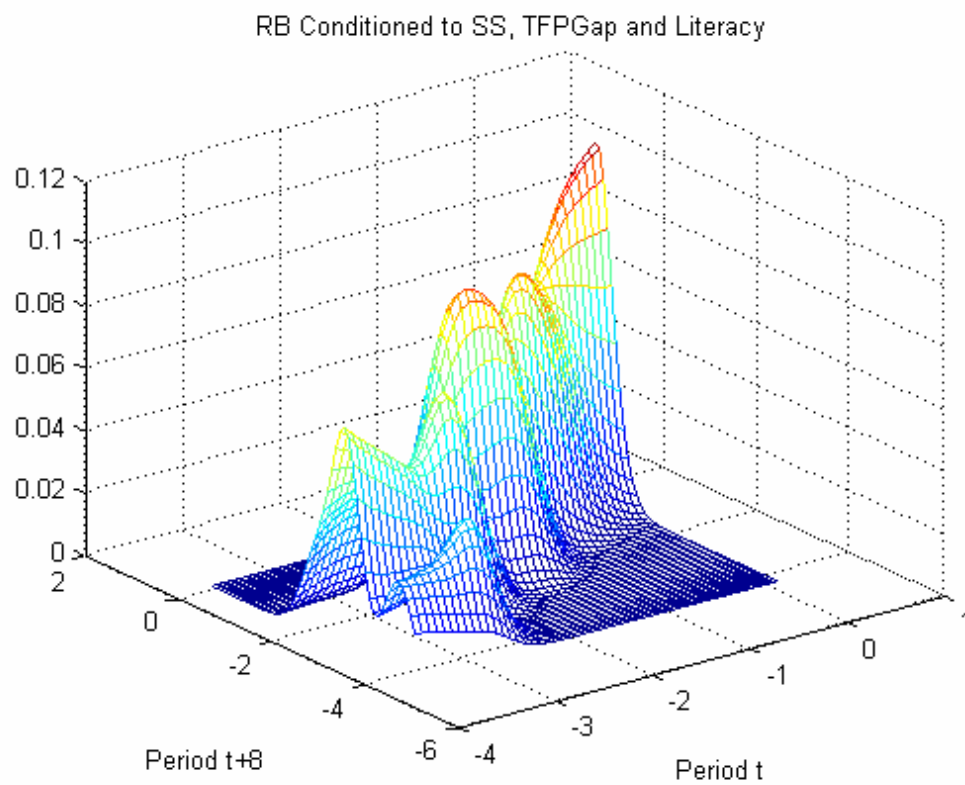
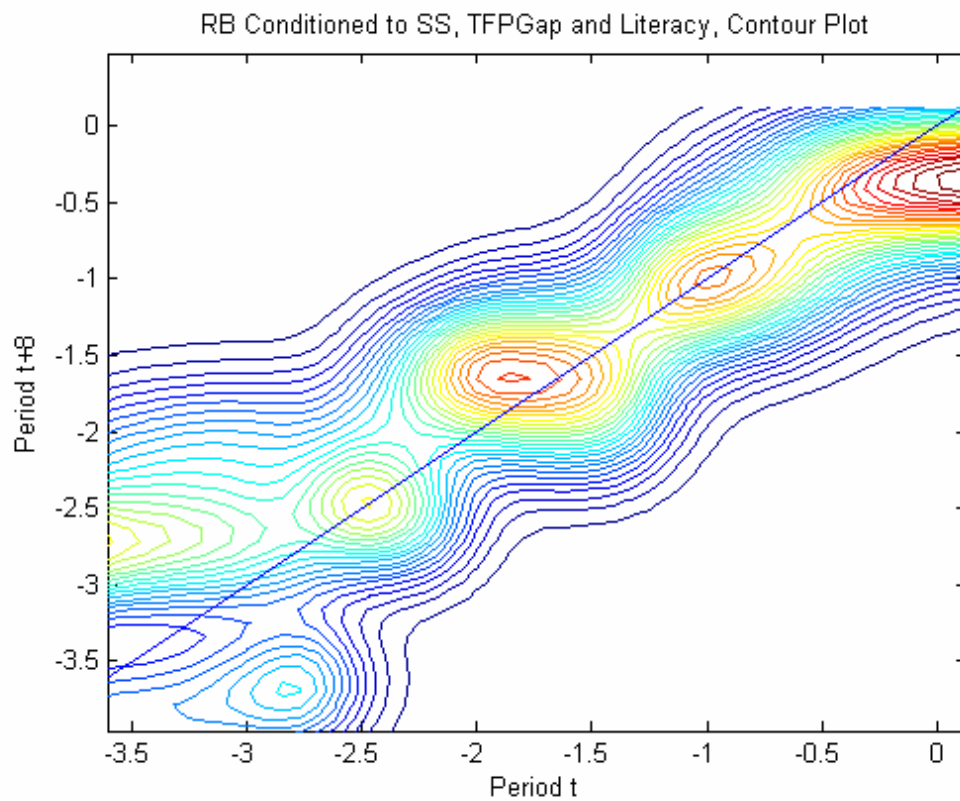
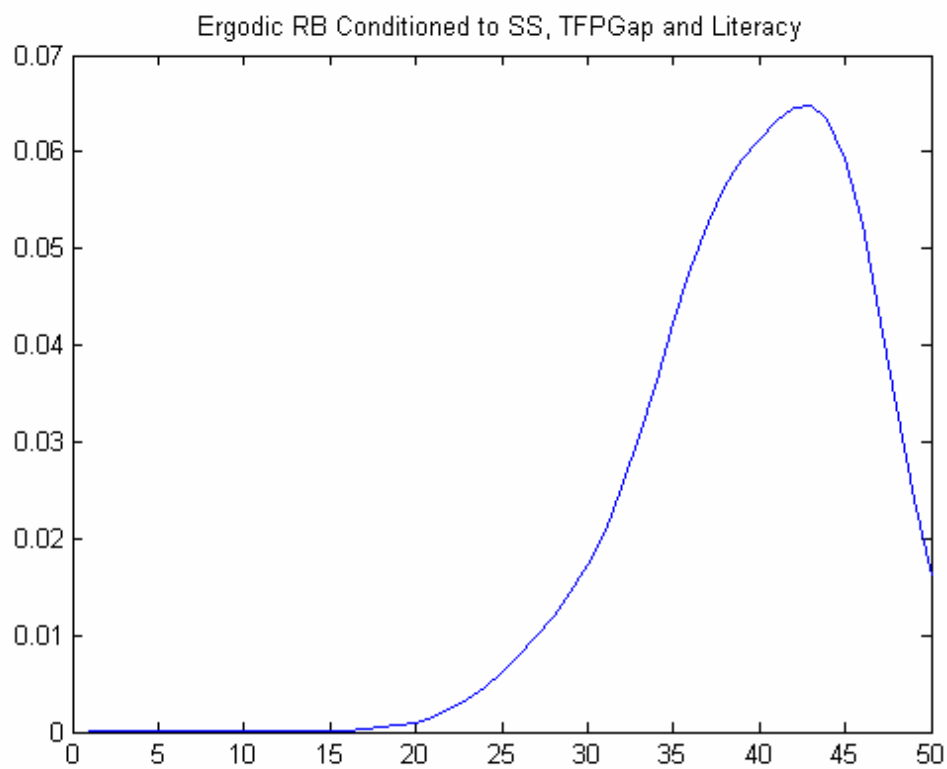


Figure 1.4.1.





**Figure 1.4.2.**



**Figure 1.4.3.**

## Low Technology

### Absolute convergence

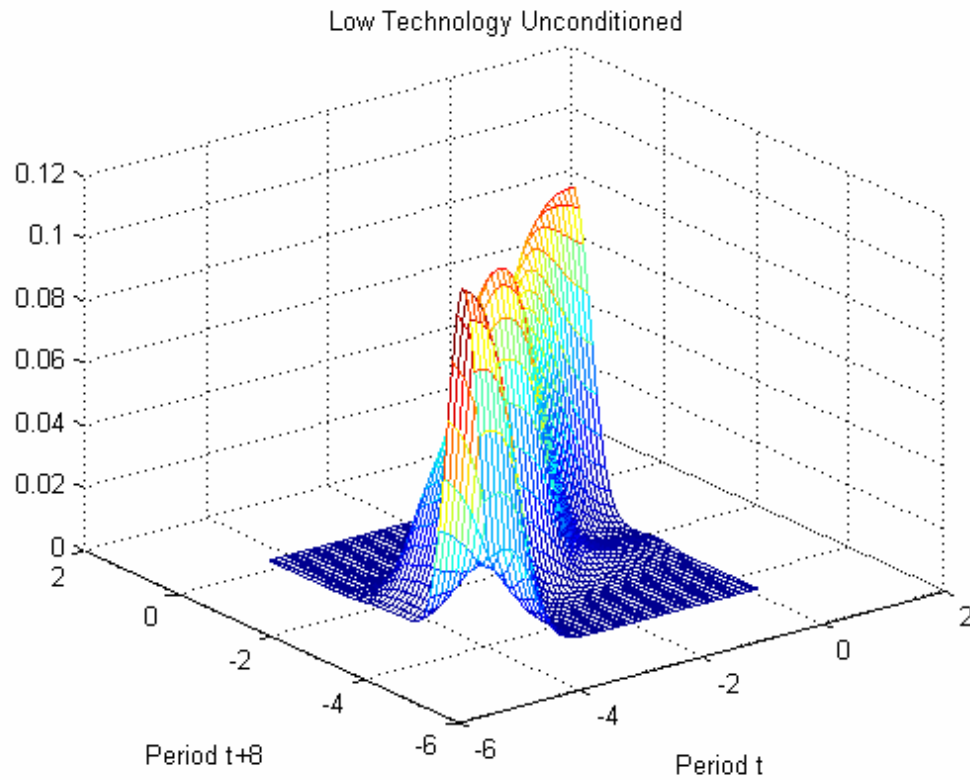


Figure 2.1.1.

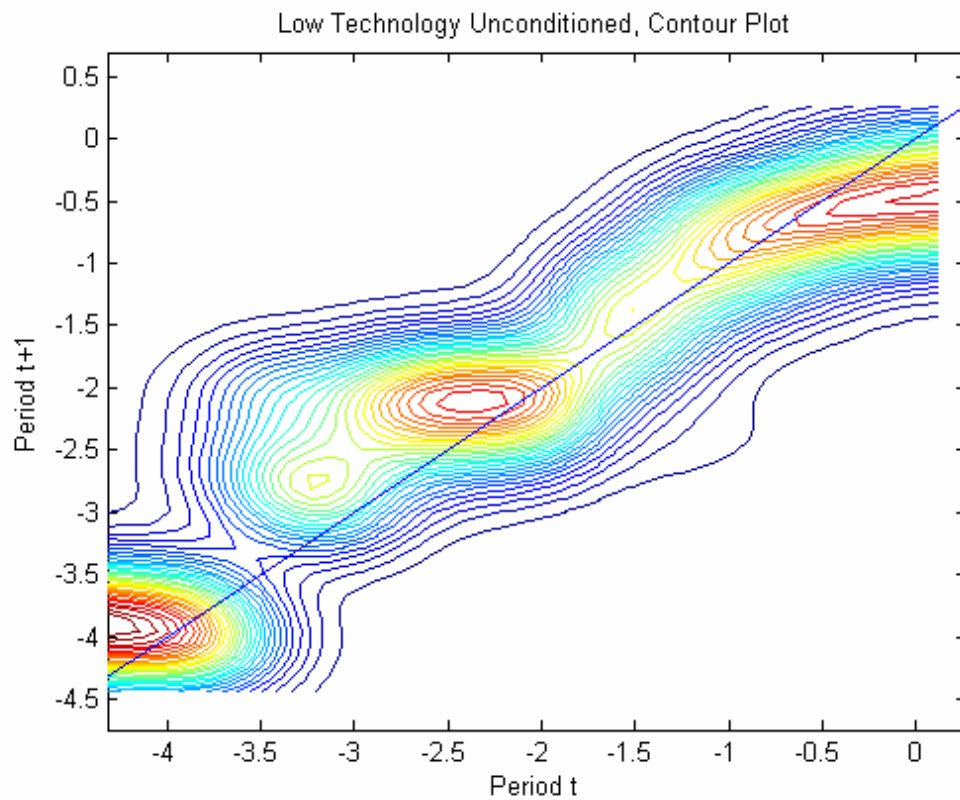
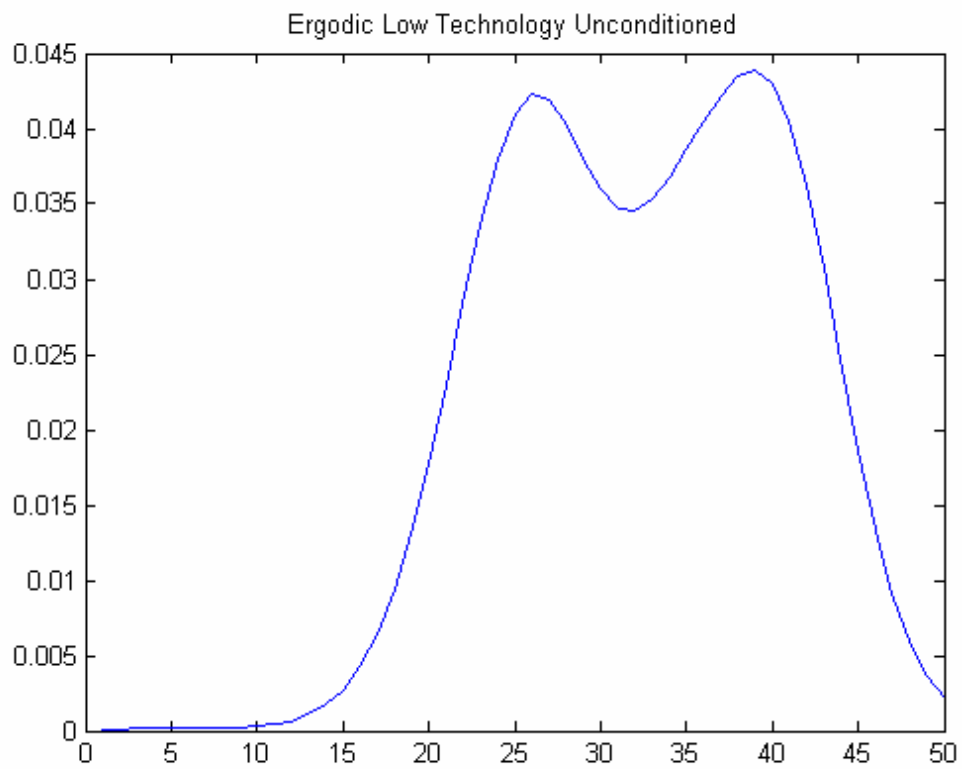
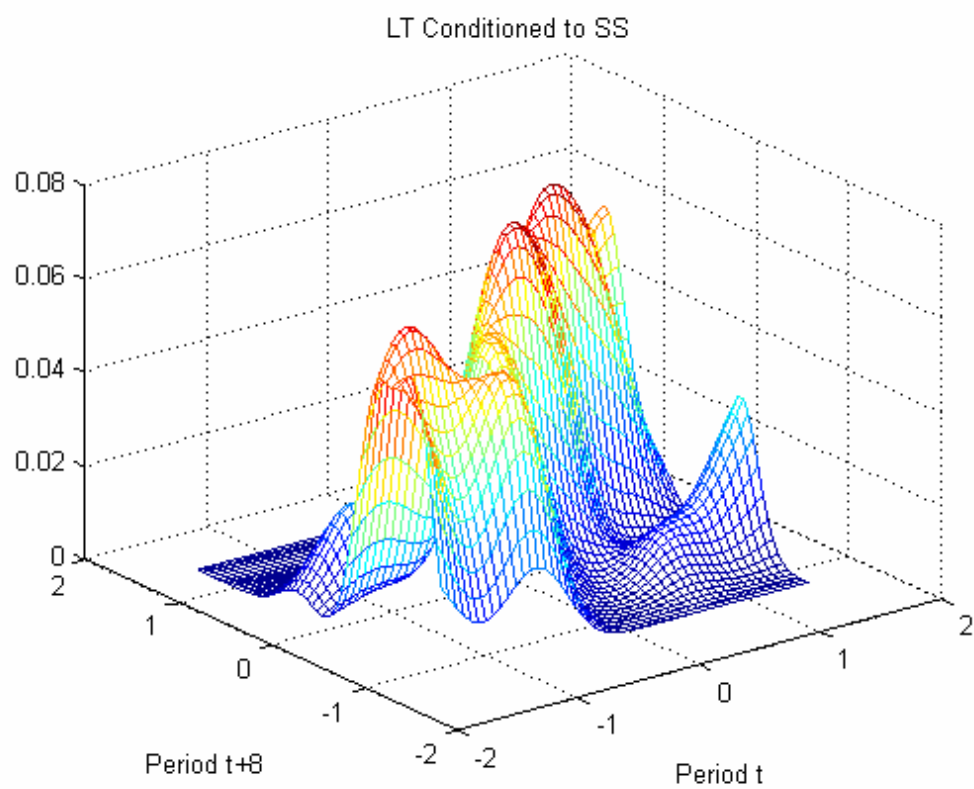


Figure 2.1.2.

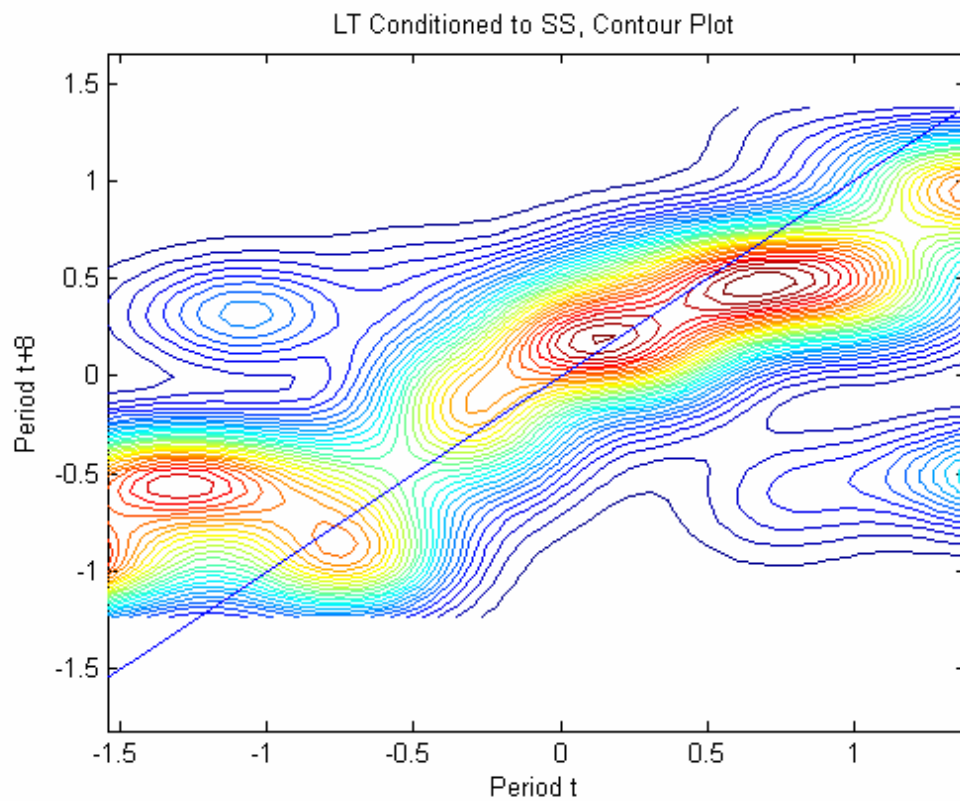


**Figure 2.1.3.**

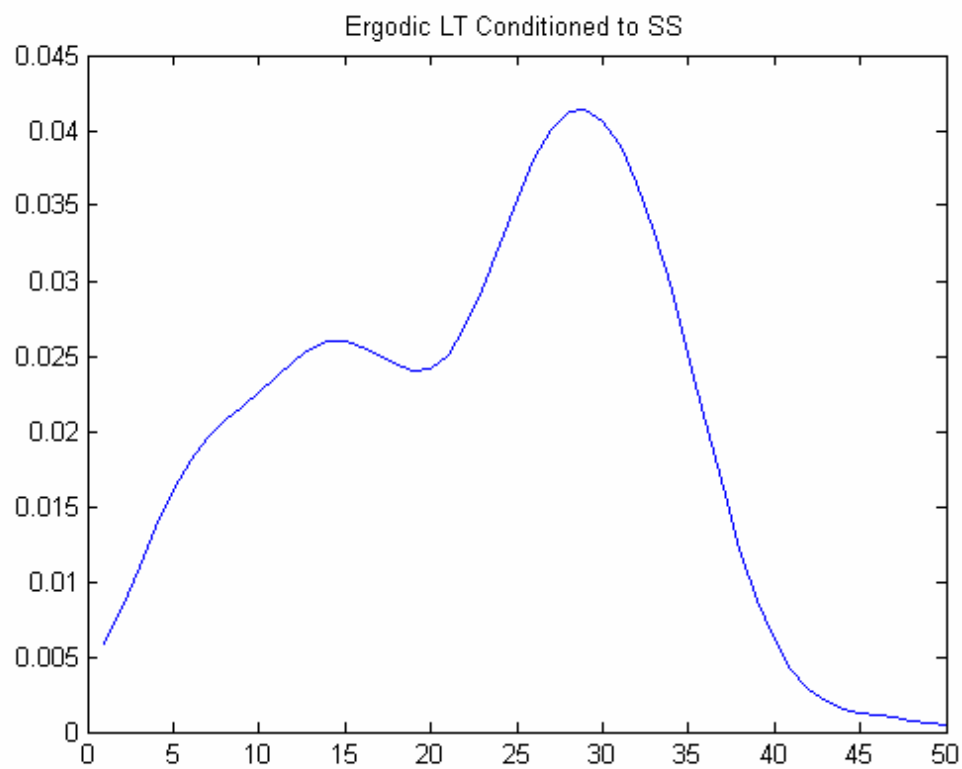
### Conditional convergence



**Figure 2.2.1.**



**Figure 2.2.2.**



**Figure 2.2.3.**

### Capital stock initial conditions as club convergence inner driver

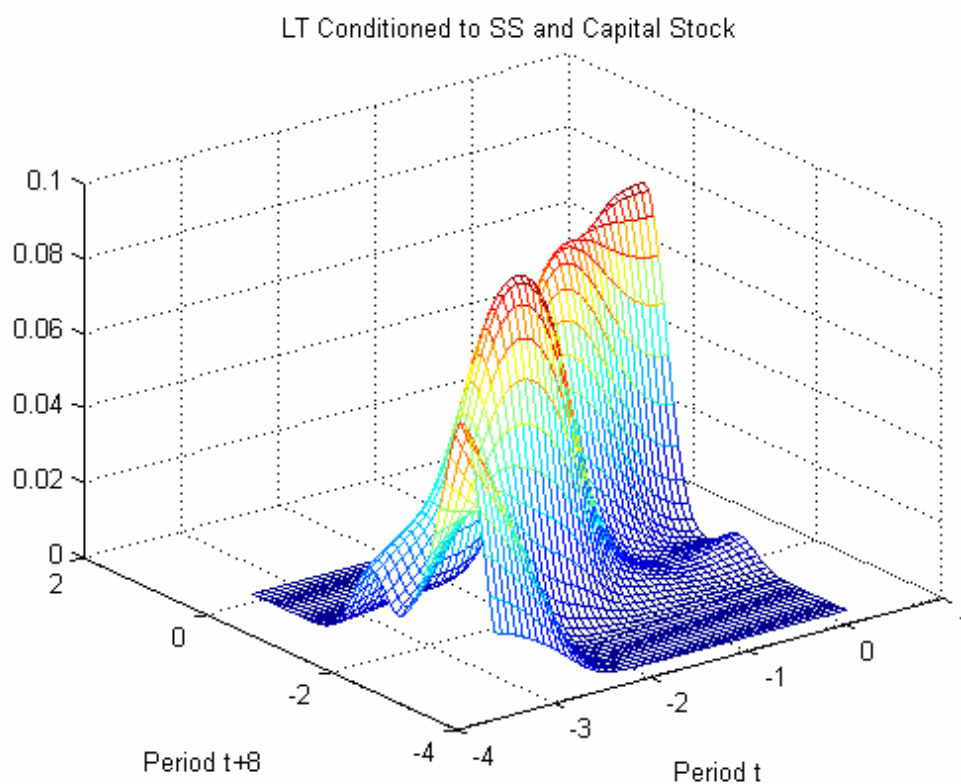


Figure 2.3.1.

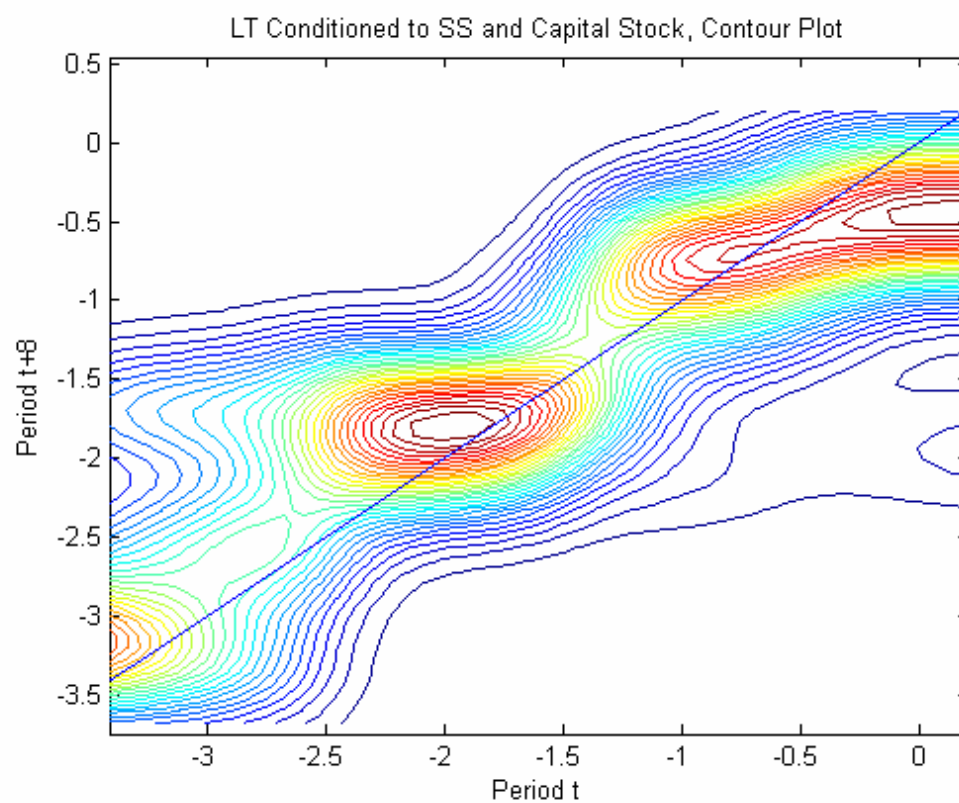


Figure 2.3.2.

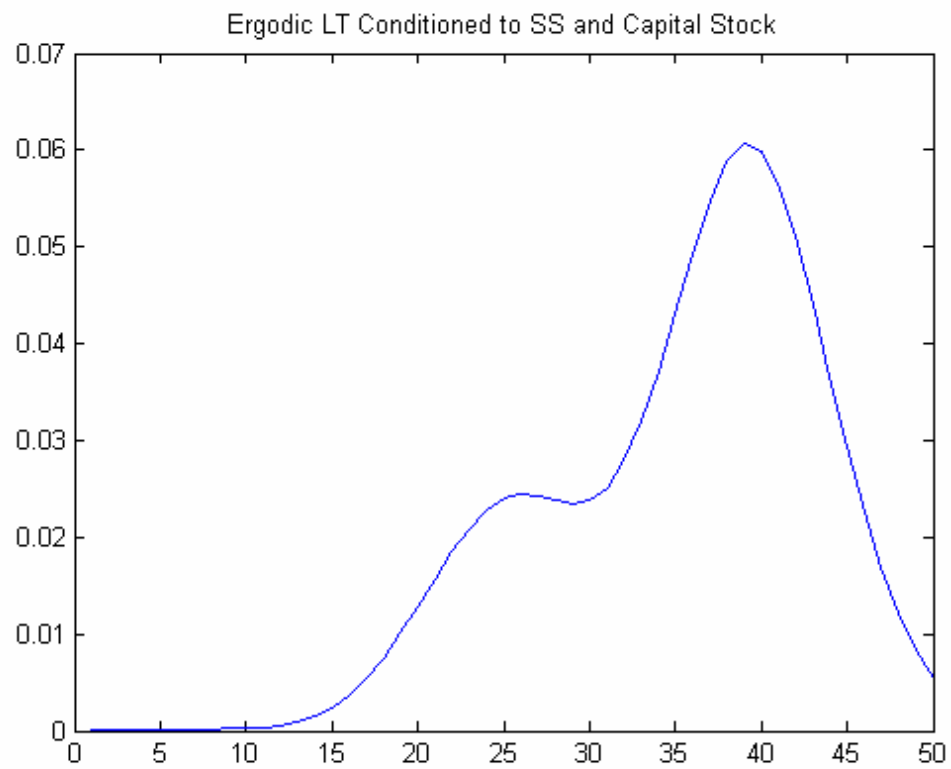


Figure 2.3.3.

### Technological initial conditions as club convergence inner driver

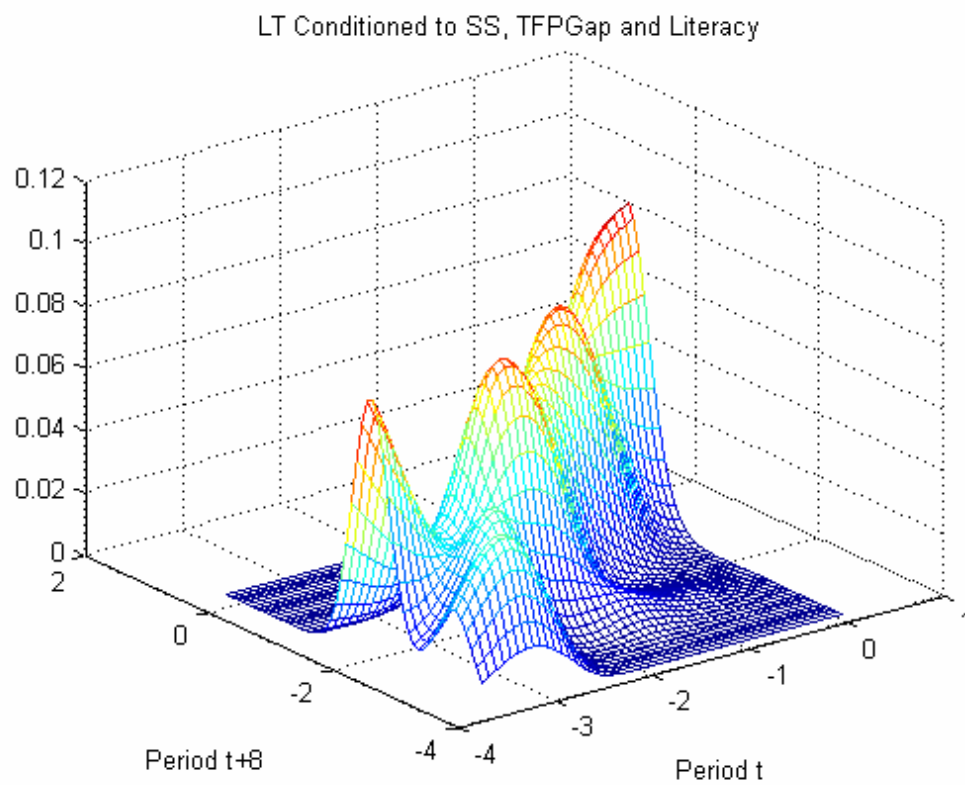
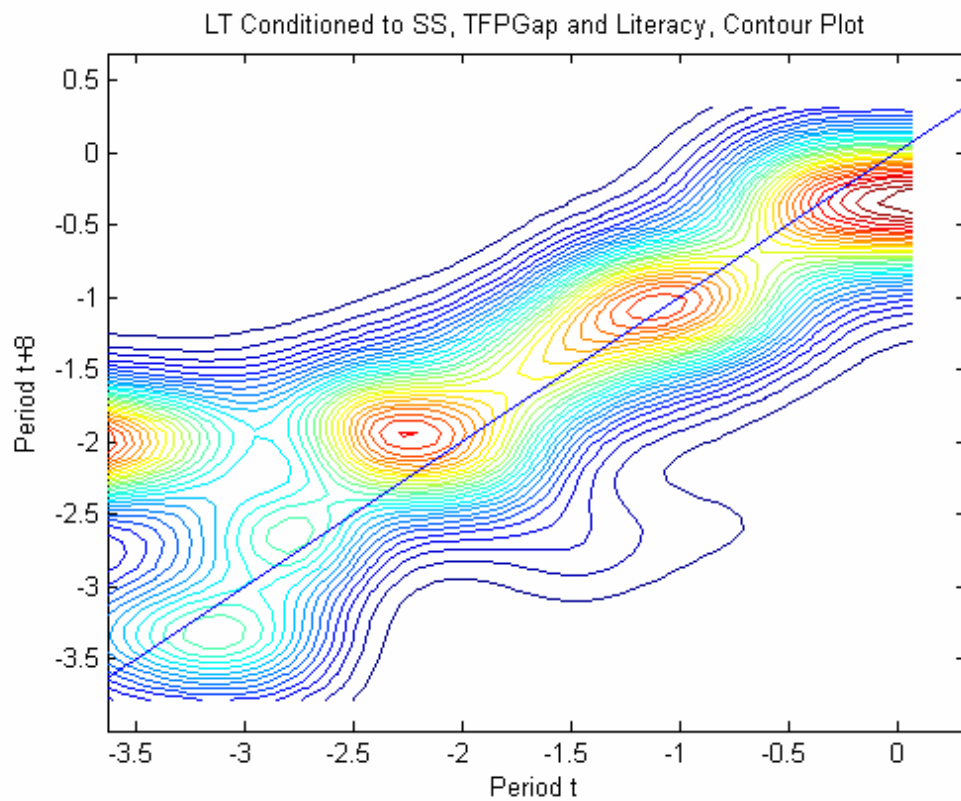
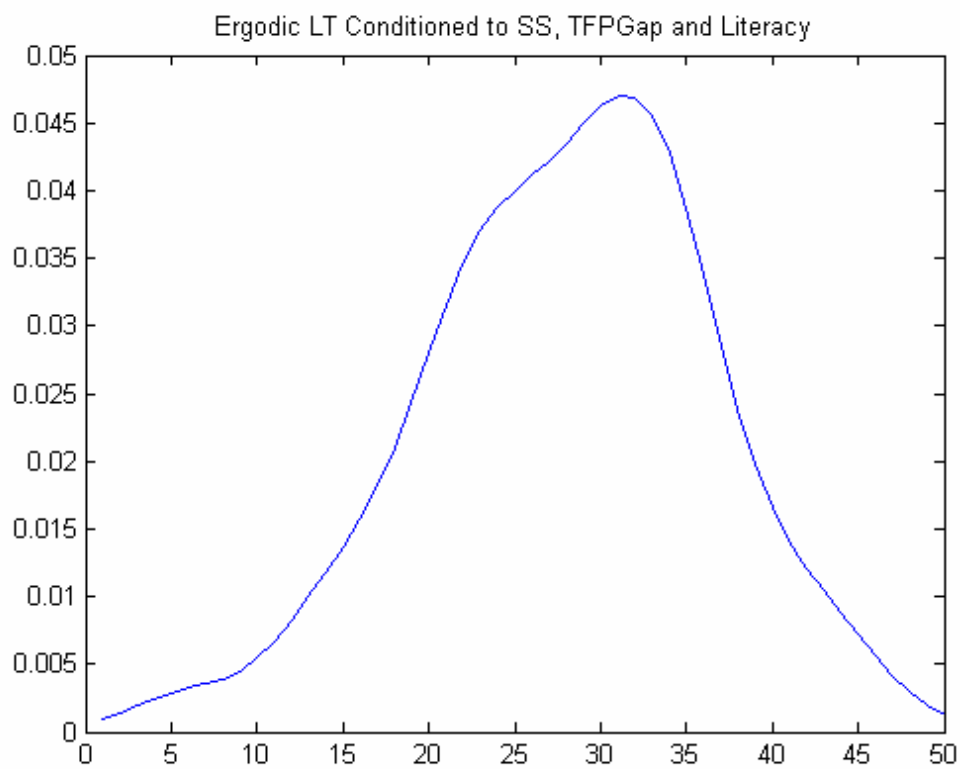


Figure 2.4.1.



**Figure 2.4.2.**



**Figure 2.4.3.**

## Medium Technology

### Absolute convergence

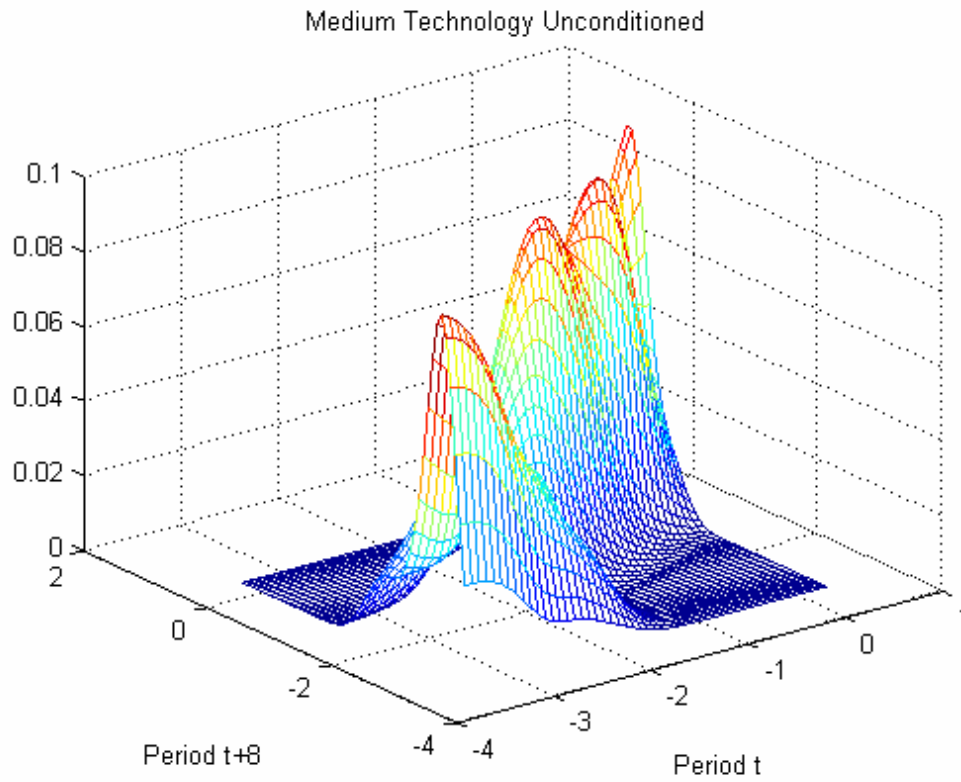


Figure 3.1.1.

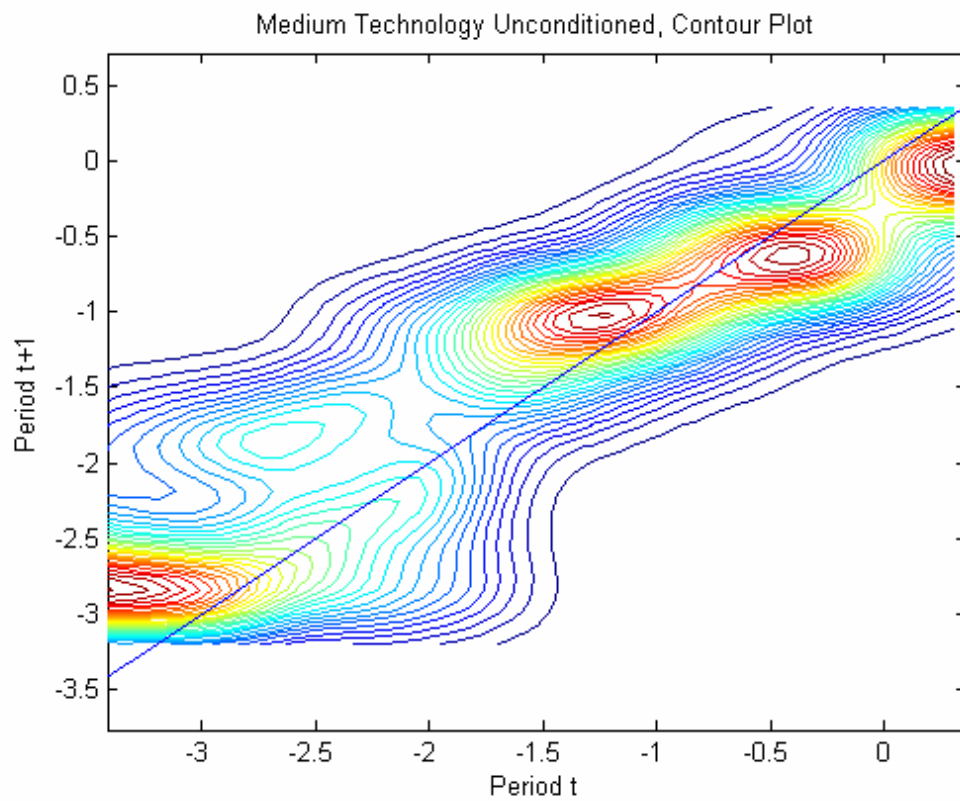
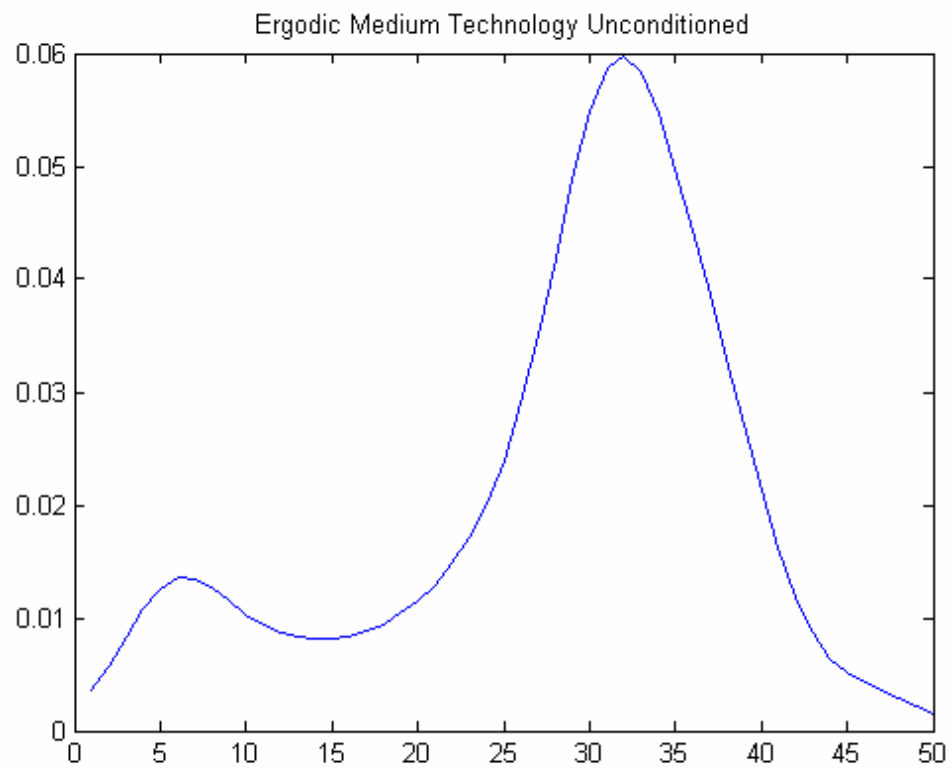


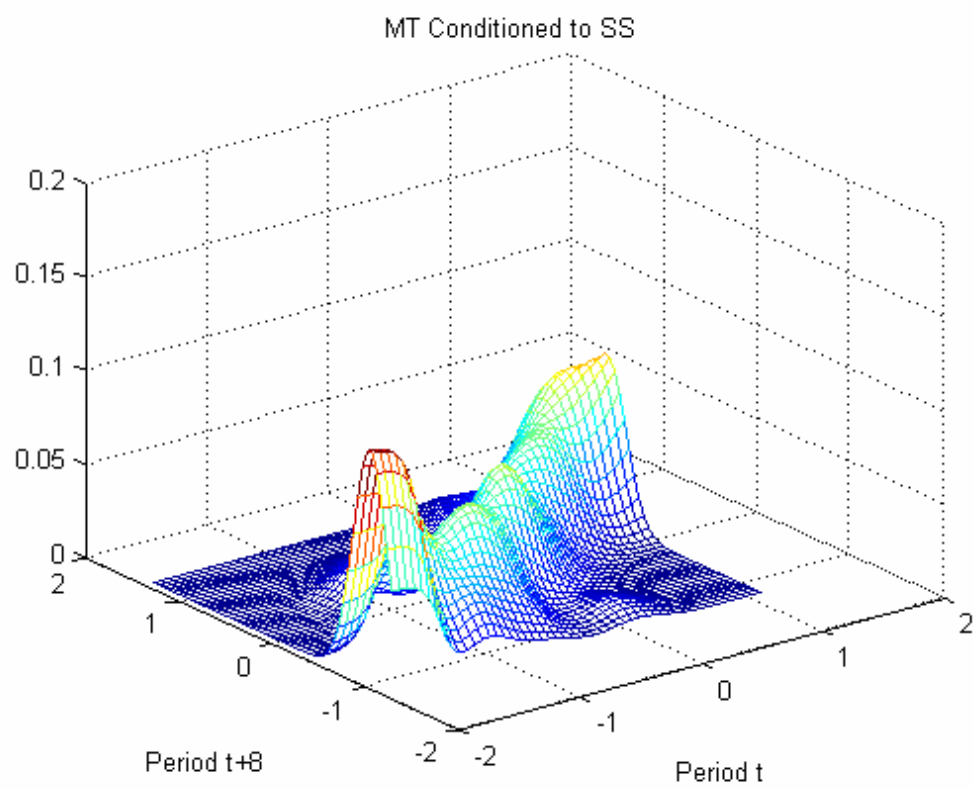
Figure 3.1.2.



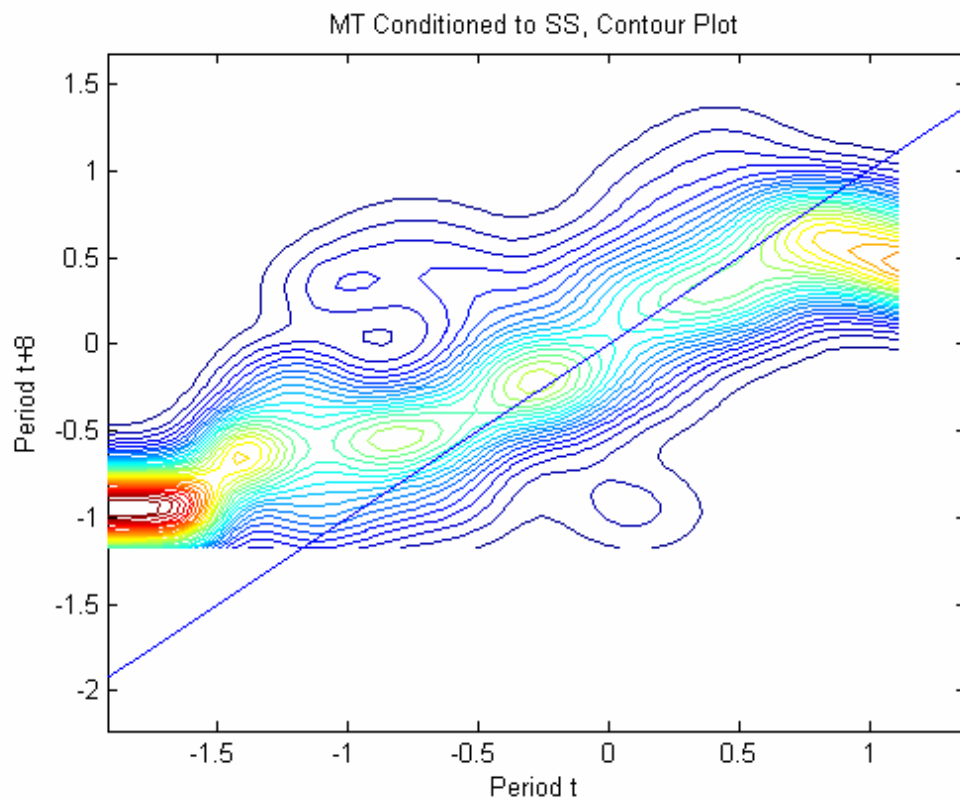


**Figure 3.1.3.**

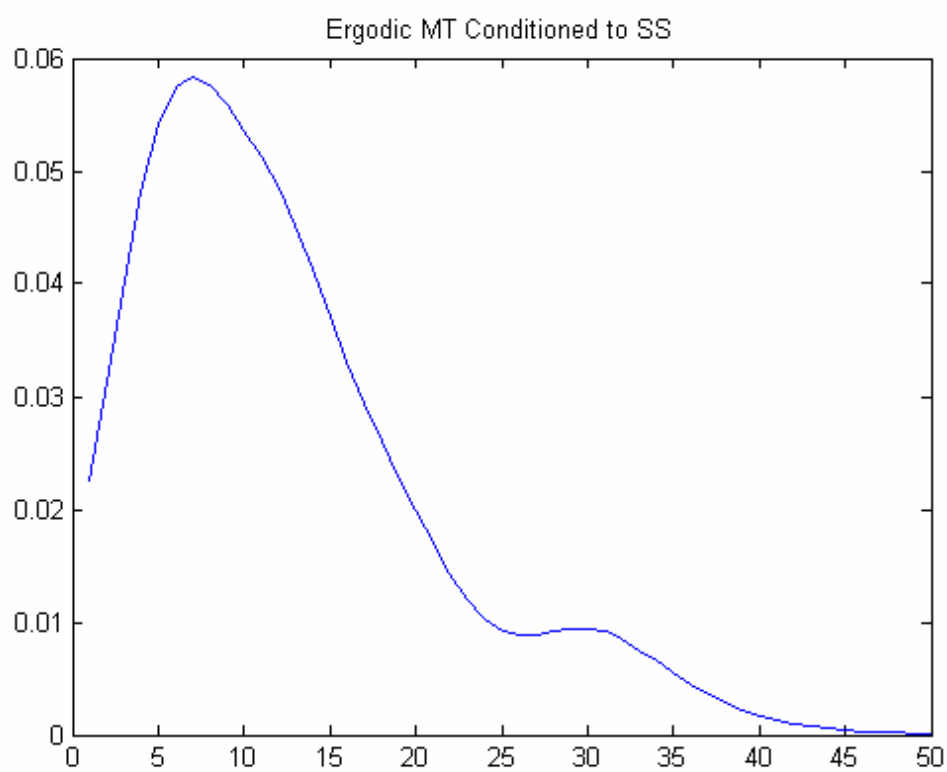
### Conditional convergence



**Figure 3.2.1.**



**Figure 3.2.2.**



**Figure 3.2.3.**

### Capital stock initial conditions as club convergence inner driver

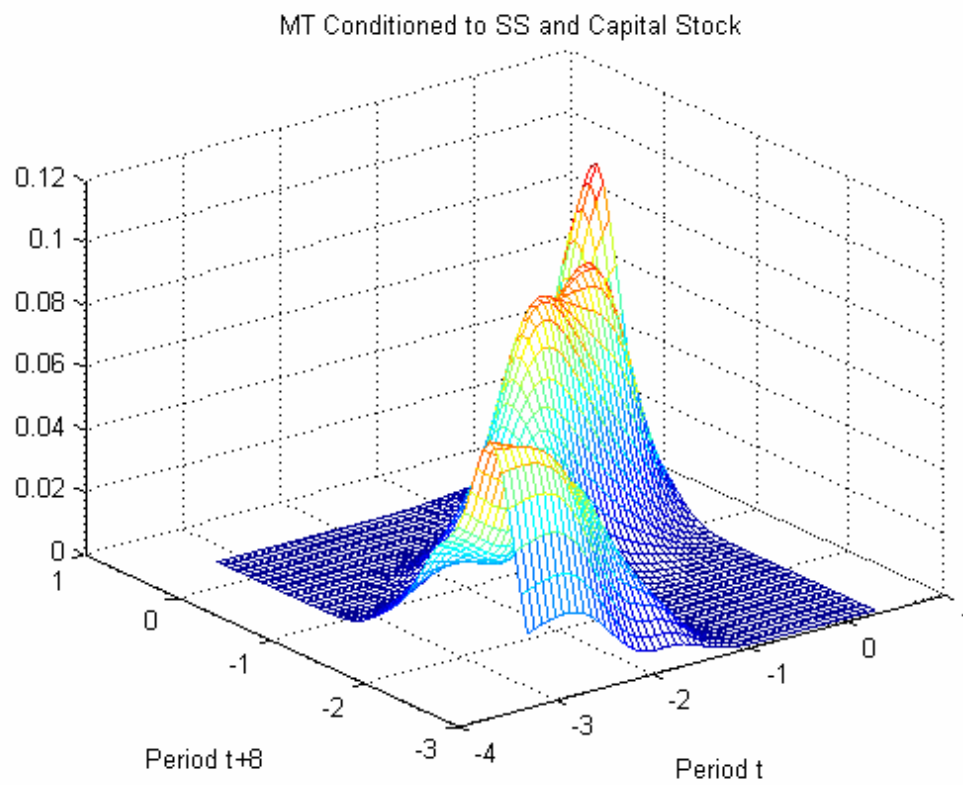


Figure 3.3.1.

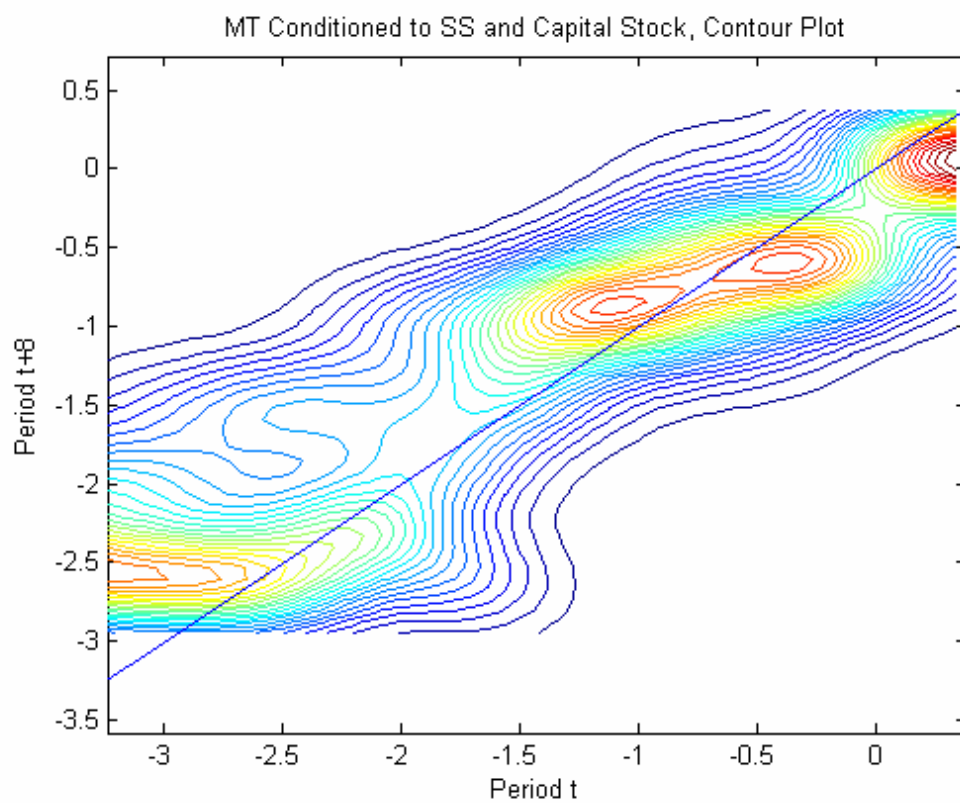
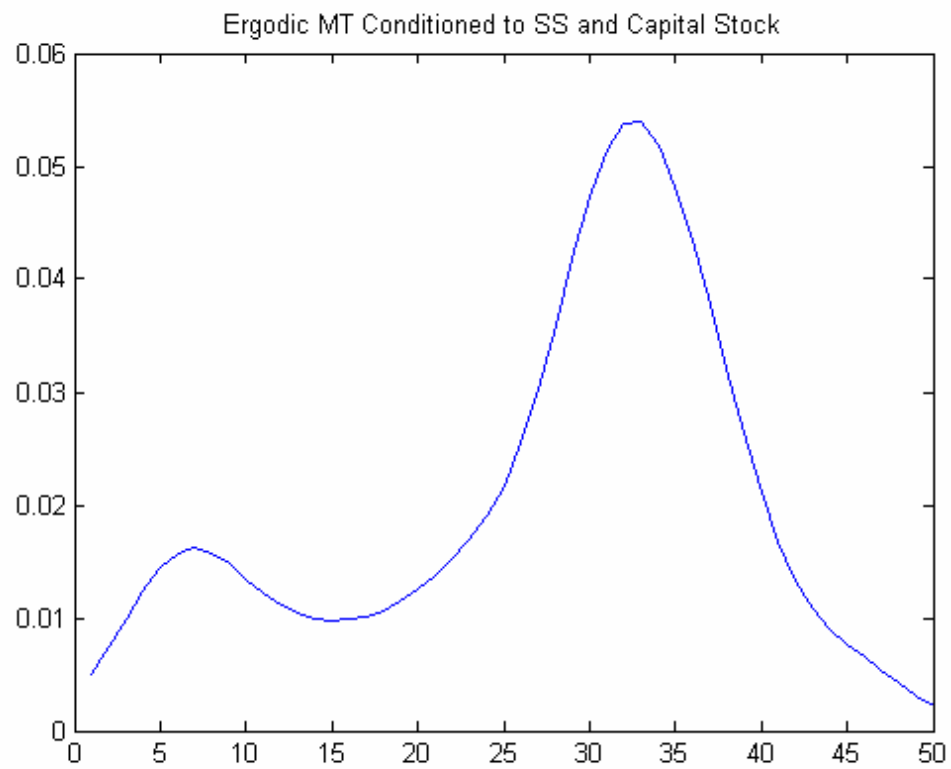
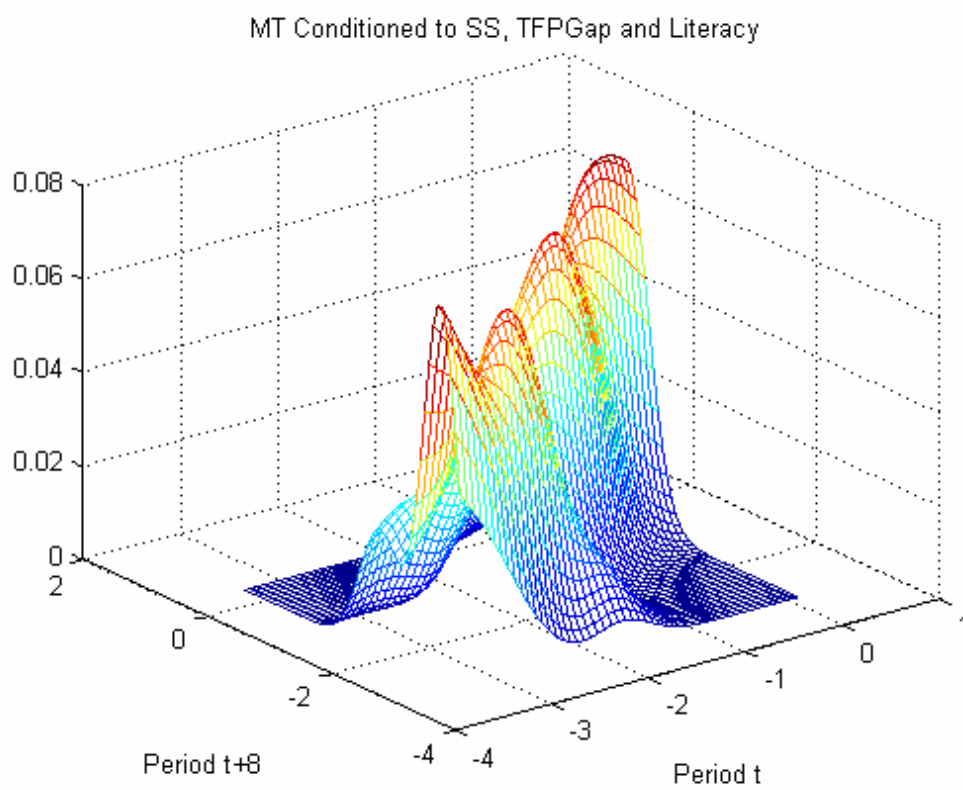


Figure 3.3.2.

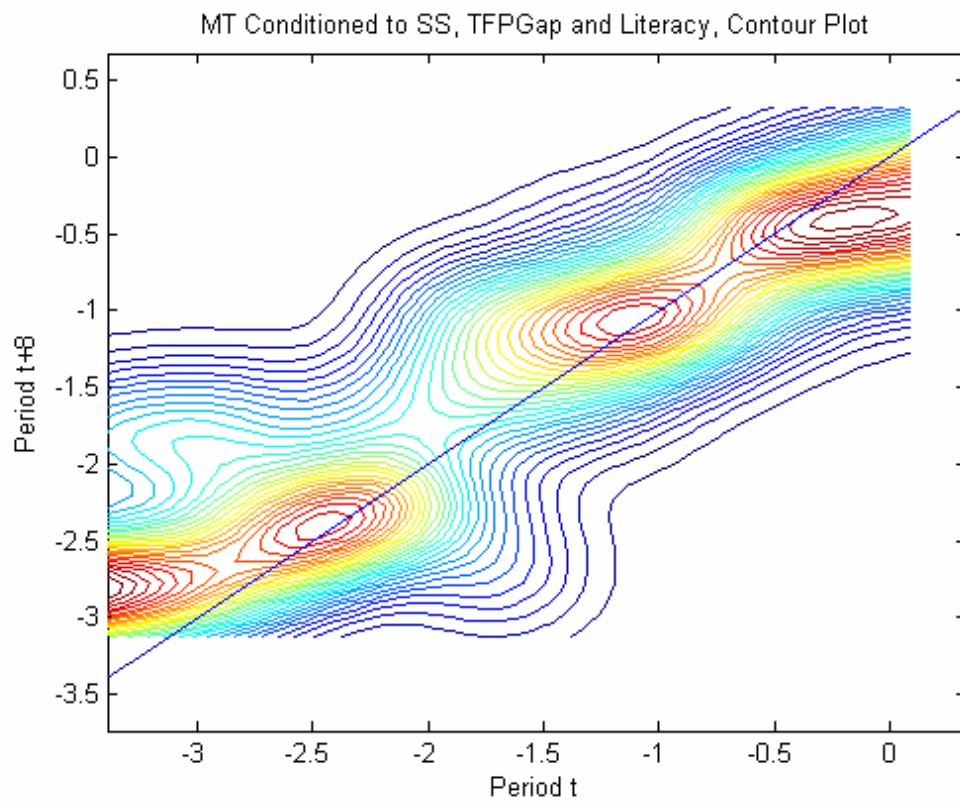


**Figure 3.3.3.**

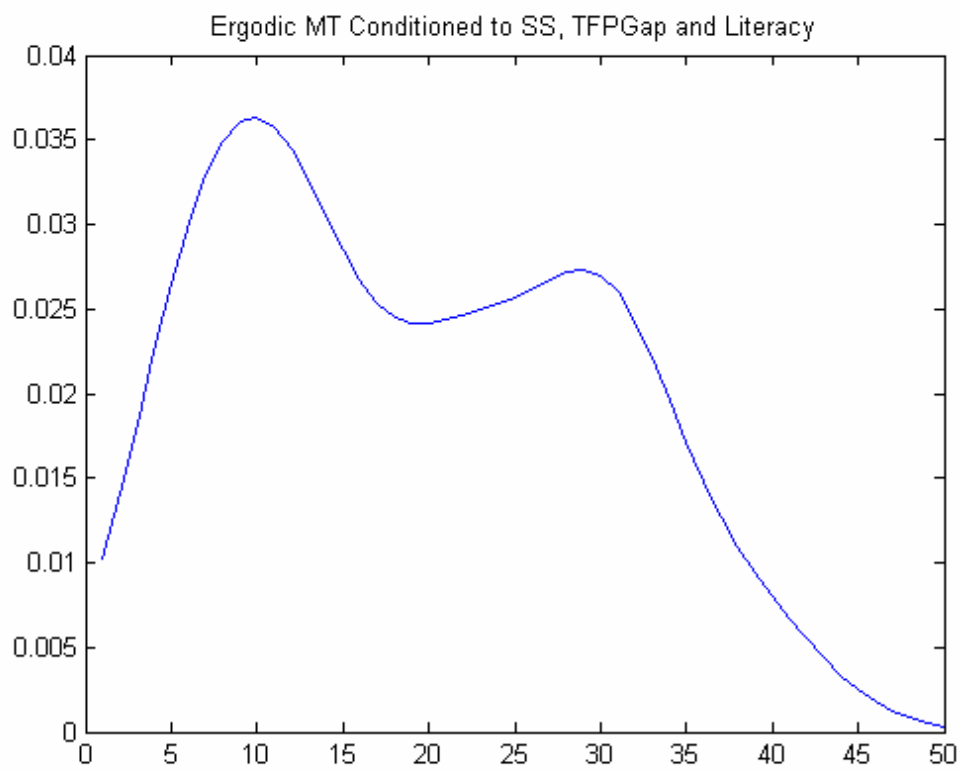
### Technological initial conditions as club convergence inner driver



**Figure 3.4.1.**



**Figure 3.4.2.**



**Figure 3.4.3.**

## High Technology

### Absolute convergence

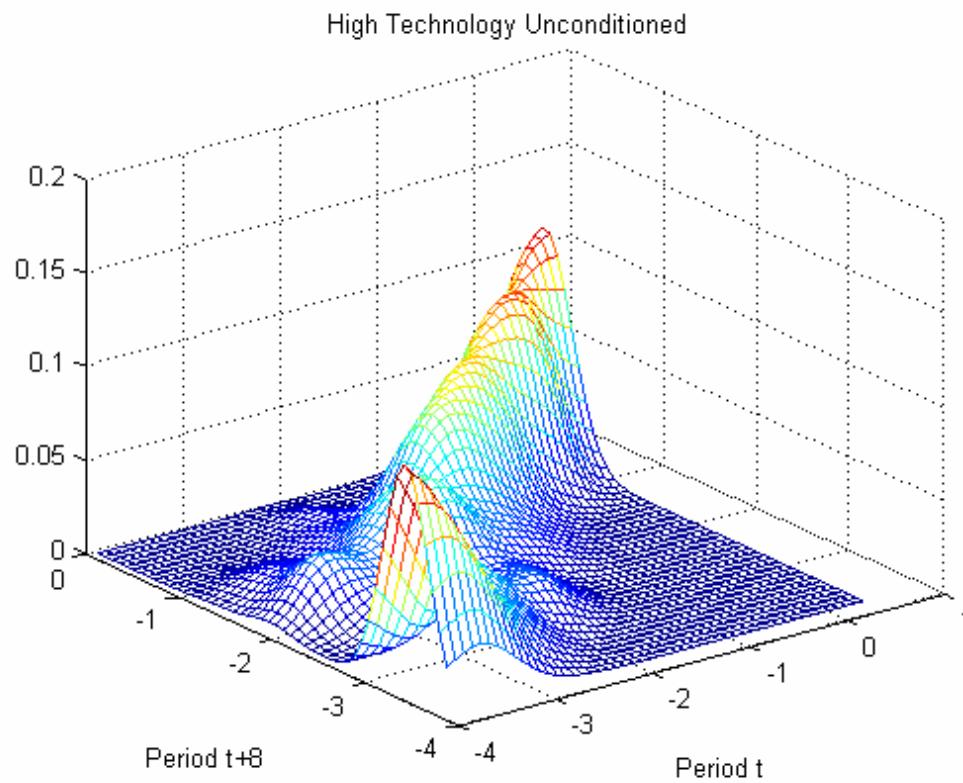


Figure 4.1.1.

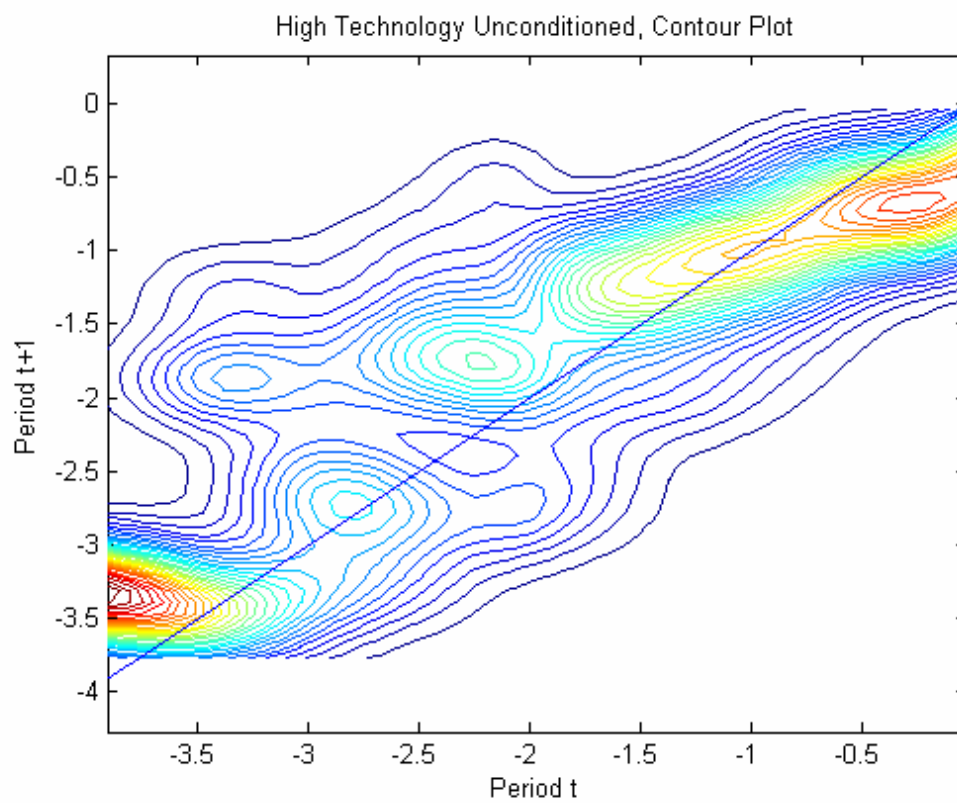
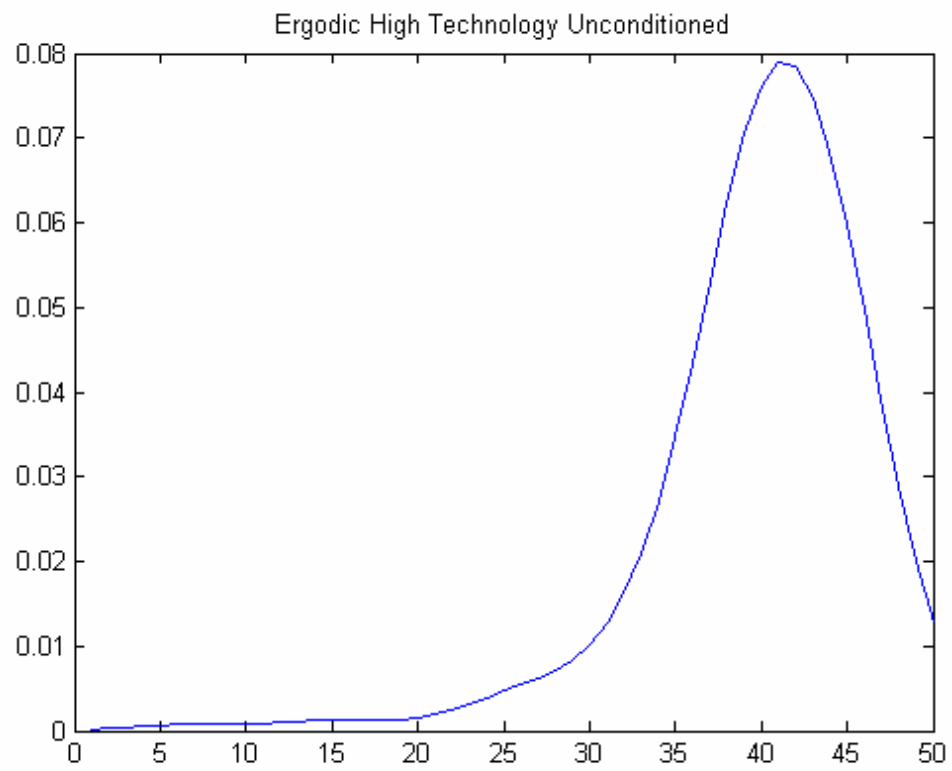


Figure 4.1.2.



**Figure 4.1.3.**

## Manufacturing

### Absolute convergence

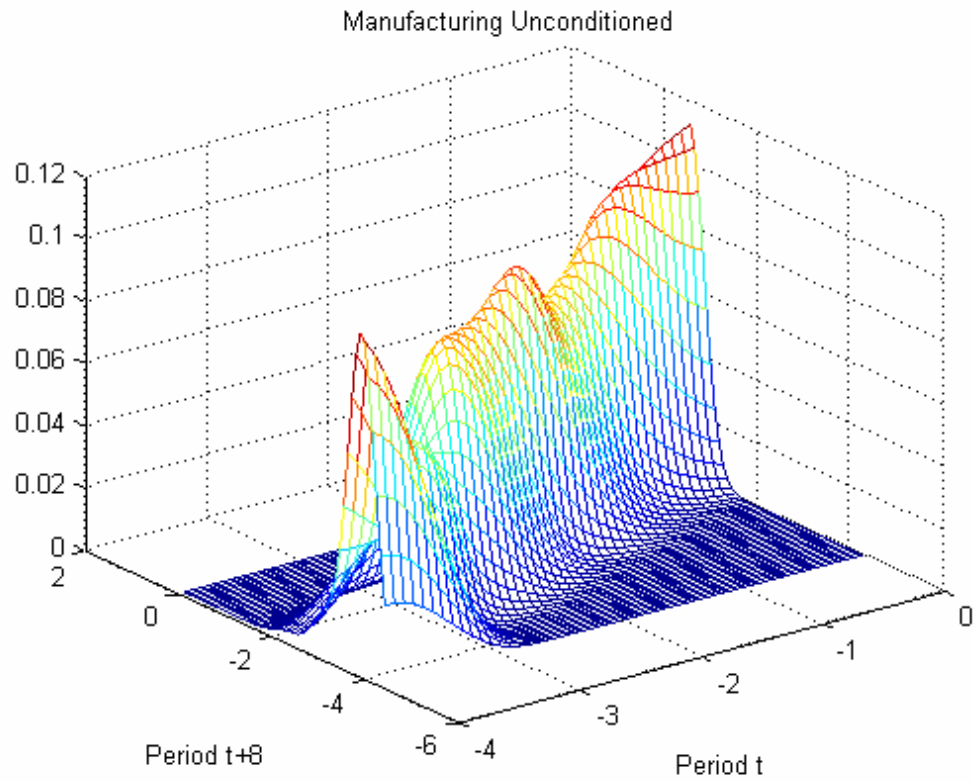


Figure 5.1.1.

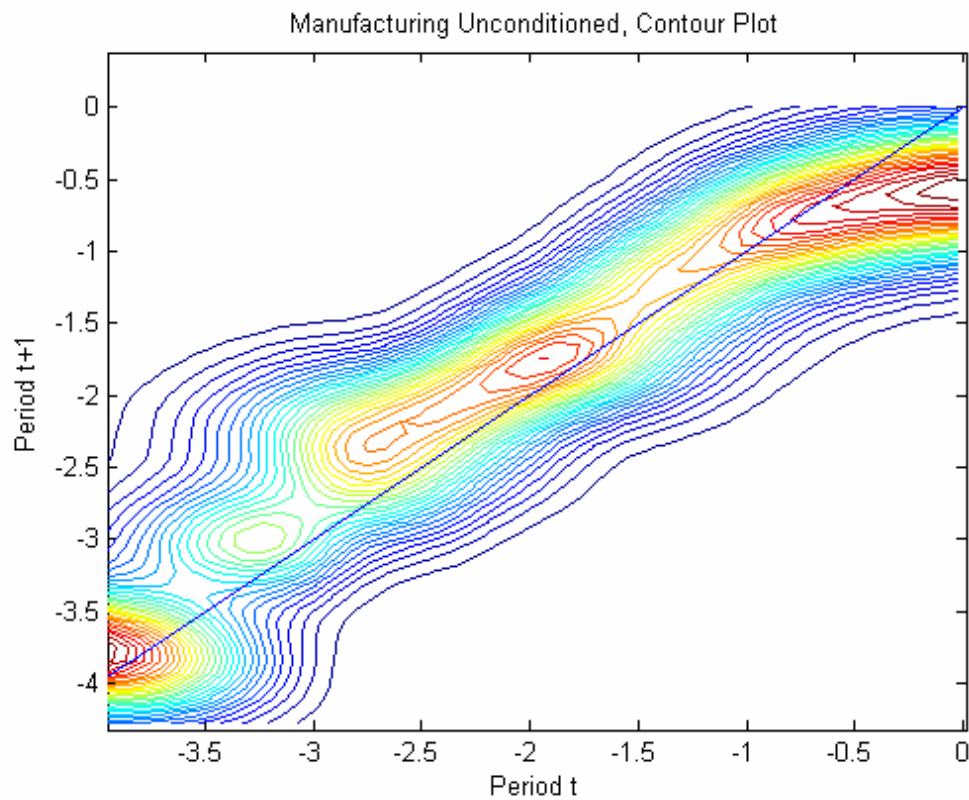
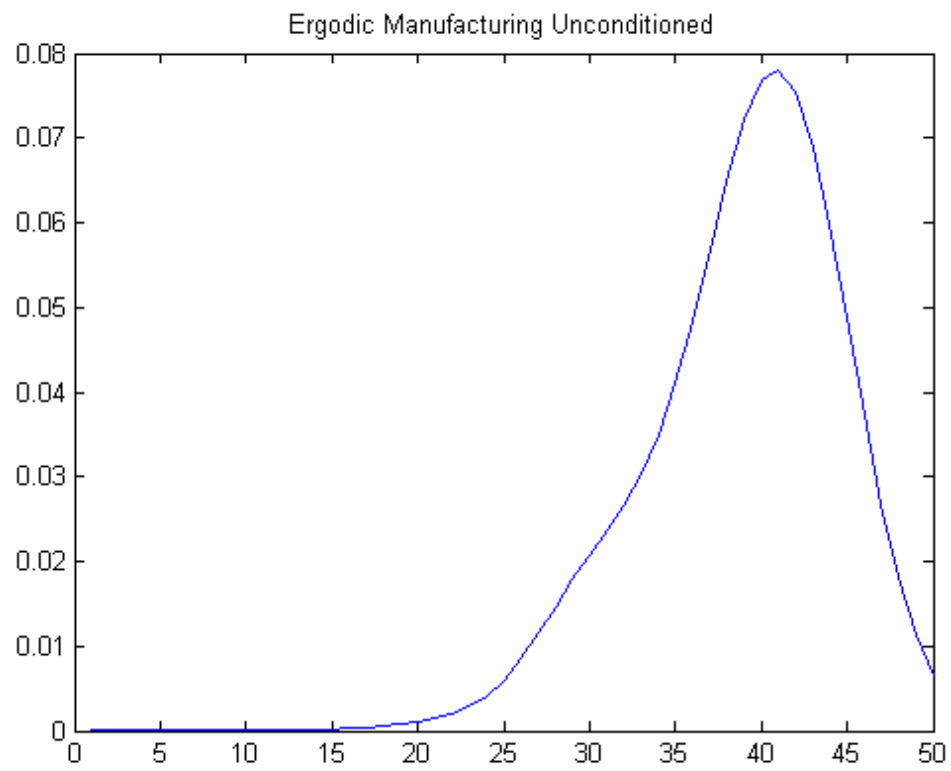


Figure 5.2.1.





**Figure 5.1.3.**