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On-the-job learning and earnings

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ON-THE-JOB LEARNING AND EARNINGS[♦]

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Résumé: Nous proposons un modèle d'apprentissage informel qui identifie deux des principales composantes de la formation en entreprise : l'apprentissage autonome et l'apprentissage par observation des autres. En reliant les gains au potentiel d'apprentissage dans l'entreprise, celui-ci révise la modélisation classique de l'ancienneté (Mincer et Jovanovic, 1981). L'estimation des paramètres structurels de ce modèle non-linéaire, à l'aide de données appariées françaises, fait apparaître, qu'en moyenne, les salariés peuvent apprendre l'équivalent de dix pour cent de leur capital humain initial et qu'il leur faut deux ans pour acquérir la moitié de ce potentiel d'apprentissage. Le potentiel d'apprentissage des individus dans leur établissement permet, à la fois au niveau des emplois et des établissements, de distinguer un secteur primaire (à forte accumulation en capital humain) d'un secteur secondaire (à faible accumulation en capital humain). Nous montrons qu'il existe une forte corrélation entre le potentiel d'apprentissage et l'ancienneté. Les prédictions de la théorie duale du marché du travail concernant l'appariement positif entre secteur primaire et salariés les plus éduqués, visibles au niveau des établissements, semble disparaître au niveau des emplois.

Mots clés: Capital humain, fonctions de gains, formation informelle, apprentissage par observation des autres, apprentissage autonome, rendements de l'ancienneté, dualisme.

Abstract: A simple model of informal learning on-the-job which combines learning by oneself and learning from others is proposed in this paper. It yields a closed-form solution that revises Mincer-Jovanovic's (1981) treatment of tenure in the human capital earnings function by relating earnings to the individual's learning potential from jobs and firms. We estimate the structural parameters of this non-linear model on a large French survey with matched employer-employee data. We find that workers on average can learn from others ten percent of their own human capital on entering the firm, and catch half of their learning potential in just two years. The measurement of workers' learning potential in their jobs and establishments provides a simple characterization of primary-type and secondary-type jobs and establishments. We find a strong relationship between the job-specific learning potential and tenure. Predictions of dual labor market theory regarding the positive match of primary-type firms (which offer high learning opportunities) with highly endowed workers (educated, high wages) are visible at the establishment level but seem to vanish at the job's level.

Keywords: Human capital, earnings functions, informal training, learning from others, learning by oneself, returns to tenure, dualism.

JEL Code: J24, J31, I2.

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I.   INTRODUCTION

The effects of human capital on earnings are commonly captured by a remarkably simple equation, which was suggested and estimated by Mincer (1974) on US Census data and is still known as the "Mincerian" earnings function. The most widely estimated version of this model is linear in education and quadratic in labor market experience: it is usually called the quadratic earnings function. An extended version of this equation, which was proposed by Mincer and Jovanovic (1981), also includes a quadratic function of tenure in the incumbent firm. This typical equation has now been estimated so many times, in so many countries, and fits the data so parsimoniously with satisfactory results, that there have been incredibly few attempts to improve its theoretical underpinnings. However, Mincer (1974) was aware that the description of post-school investment was the weak point of his theoretical construction:

"[…] the most important and urgent task is to refine the specification of the post-school investment category […] to include details (variables) on a number of forms of investment in human capital."

Mincer (1974) was conscious that a variety of learning processes took place within firms, but he was severely constrained by the available data sets at the time he wrote. As it stands, the Mincerian earnings function incorporates some of the major implications of optimal human capital models but it does not derive from the worker's optimizing behavior described by these models, since the investment profiles are assumed exogenously. Furthermore, and this is perhaps even more disquieting, it treats human investments in school and on-the-job exactly alike. However, in contrast to investments in schooling, the supply of informal training is tied into the workers' labor contract. As Rosen (1972) remarked long ago, each firm provides a specific package of training services to its workers so that the latter, once they entered a firm, have no other choice than to acquire its knowledge. The time has come to think of incorporating the informal diffusion of knowledge within firms into the Mincerian earnings function because large matched employer-employee data sets are now available (Abowd and Kramarz, 1999). We shall be using here a unique French survey on labor cost and wages structure (INSEE 1992) comprising 150 000 wage earners in 16 000 establishments. On the theoretical side, we explicitly model two informal learning processes on-the-job in an attempt to capture both unsystematic and systematic components. We designate the unsystematic part as "self-learning" and the systematic part as "learning by watching" or "learning from others". Barron, Black and Loewenstein (1989) confirms the

importance of these informal learning processes in the U.S. In the three months following the recruitment of new workers, 96% of on-the-job training is given to them in an informal way by other workers (145.2 hours of a total 151.1 hours) and more than one-third of on-the-job training (53.1 hours) is provided through a "learning by watching" process. Learning by oneself through experience and learning from others seem to capture the essential ingredients of informal learning on-the-job, so that a model that incorporates these two elements should offer a good description of informal on-the-job training. They both form the microeconomic counterparts of the autonomous and catch-up growth processes separated by Benhabib and Spiegel (1994) in macroeconomic growth models, following a suggestion of Nelson and Phelps (1966). We extend here the model of learning by watching presented by Lévy-Garboua (1994), by incorporating self-learning. Previous tests of the learning-by-watching model on various data sets have appeared in Chennouf, Lévy-Garboua et Montmarquette (1997), Nordman (2000), and Destré (2000). This paper presents the first test of the extended model of earnings on a large data set.

The paper is organised as follows. After presenting the model in section 2, the data and the econometric approach are discussed in section 3. Section 4 discusses the main results, and section 5 concludes.

II. A MODEL OF ON-THE-JOB LEARNING

Workers may acquire training formally or informally. Both kinds of training are costly as they take time away from more productive tasks. The main difference between them seems to be that purely informal learning, unlike formal training, does not consume any resources from other workers[1]. As a result, employees who are getting or supplying informal training may not always be conscious that they are doing so[2]. Workers learn informally on-the-job, either by themselves (*i.e.* through their own experience) or by watching others. "Self-learning" on-the-job enhances productivity by a trial-and-error process, and the productivity gain should be highly correlated with human capital since the more qualified workers are

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[1] Like formal training, informal training consumes non-labor resources of the firm. When non-labor costs can be neglected, informal training is freely supplied by firms if workers under training pay for the foregone value of their own time.

[2] This is consistent with the finding (Barron, Black and Berger, 1997) that employees underestimate the amount of informal training they received by 20% relative to employers.

likely to adopt innovations faster. "Watching" the more productive workers do their own job also enhances the productivity of a less productive worker by a simple imitation process, at no cost for her "teachers". This is a kind of externality which, for two main reasons, does not call for a direct compensation of the teachers. First, it is a diffuse process in which many teachers may interact with many students without even realizing that they supply training services, as they suffer no cost. Second, today's students will normally become tomorrow's teachers and so repay what they received in the past.

A.   A gross earnings function

Wage rates are assumed to equal the value of marginal product of labor on a competitive market. Thus, gross earnings reflect human capital. Let us designate tenure in the incumbent firm as t, expressed in discrete time, and human capital by the end of period t as h_t. With these notations, h_0 represents the level of human capital on entering the firm, that is after x periods of experience on the labor market in *other* firms. Total experience of work is $x+t$. Worker i interacts with other workers from the same firm j but she learns only from those who possess more human capital than herself. Let H_{ijt} be the highest level of human capital embodied in an employee that she is exposed to and can learn from in the same firm. It summarizes the firm's knowledge as far as worker i is concerned. By definition, $H_{ijt} \geq h_{ijt}$. For the ease of exposition, the worker's index i and the firm's index j will be omitted when this raises no confusion. The combined effects of own experience and learning from others on a worker's productivity in period t are assumed additive in the small and given by:

$$(1) \qquad h_t - h_{t-1} = gh_{t-1} + \frac{n}{1+n}\left(H_{t-1} - h_{t-1}\right)$$

In this equation, the effect of self-learning is proportional to the stock of human capital when the period begins. The factor g is net of the physical depreciation rate of human capital and it is assumed to be constant. It might be negative if the rate of depreciation exceeded the constant rate of self-learning, but we expect it to be normally positive. While experience tends to increase the human capital of all workers at a constant rate, the presence of others is presumably more beneficial to less qualified workers who have a lot to learn, if n ($n>0$), the

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rate of knowledge diffusion within the firm, is identical for all workers. For simplicity, this assumption will be kept here[3]. Moreover, n is invariant with respect to tenure.

We can now solve the recurrence equation (1) after postulating that the structure of knowledge (human capital) and the diffusion process within the firm are time-invariant. We first rewrite:

$$(2) \qquad h_t = \left(g + \frac{1}{1+n} \right) h_{t-1} + \frac{n}{1+n} H_{t-1}$$

If $g=0$, *i.e.* in the pure learning-by-watching case studied by Lévy-Garboua (1994), h_t is simply a weighted average of h_{t-1} and H_{t-1}. Moreover, the firm's job-specific knowledge is time-invariant (*i.e.* $H_{t-1} = H$) because the most qualified worker in this job category can learn neither from experience nor from others. In this case, the human capital of a worker increases with tenure and converges towards the firm's job-specific knowledge:

$$(3) \qquad h_t = \frac{1}{(1+n)^t} h_0 + \left(1 - \frac{1}{(1+n)^t} \right) H$$

with $H \geq h_0$.

In the general case ($g \neq 0$), when self-learning and learning from others combine, h_t is not a weighted average of h_{t-1} and H_{t-1}: the total of their coefficients is $1+g$. Putting this total in factor, we derive from (2):

$$(4) \qquad h_t = (1+g) \left[\frac{1 + g(1+n)}{(1+g)(1+n)} h_{t-1} + \frac{n}{(1+g)(1+n)} H_{t-1} \right]$$

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[3] This is actually not a serious problem if we hypothesize that the rate of knowledge diffusion depends solely on the schooling level, which remains constant over lifetime. This is indeed a plausible assumption because it is the role of education to enhance the ability to learn, not that of on-the-job training. Damoiselet and Lévy-Garboua (2000) develop a theory of educational systems based on this distinction.

The term in brackets is now a weighted average of h_{t-1} and H_{t-1}, which looks again like the pure learning by watching case. However, the firm's job-specific knowledge now grows with experience if the distribution of knowledge is maintained constant within the firm:

$$(5) \qquad H_t = (1+g)H_{t-1}$$

with $h_t \leq H_t \;\; \forall t \geq 0$. By recurrence, we derive from (4) and (5) the general solution of equation (1):

$$(6) \qquad h_t = k^t h_t^m + (1-k^t)H_t$$

with:

$$(7) \qquad H_t = (1+g)^t H_0 \;\; ; \;\; h_t^m = (1+g)^t h_0 \;\; \text{and} \;\; k = \frac{1+g(1+n)}{(1+g)(1+n)}$$

In (6) and (7), h_t^m designates the value of gross earnings predicted by a linear-in-tenure version of the Mincerian earnings function. Equation (6) nests equation (3), if $g=0$. The human capital of any given worker increases with tenure and converges towards the firm's job-specific knowledge. However, the latter is a moving target, which increases at a steady rate.

B. The returns to tenure

The (gross) marginal returns to tenure for a worker i employed in firm j (R_{ijt}) are easily derived from (1) for $t \geq 1$:

$$R_{ijt} = \frac{h_{ijt} - h_{ij,t-1}}{h_{ij,t-1}} = g + \frac{n}{1+n}\left(\frac{H_{ij,t-1}}{h_{ij,t-1}} - 1\right)$$

and (6) readily yields:

$$\frac{h_{ijt}}{H_{ijt}} = 1 + \left(\frac{h_{it}^m}{H_{ijt}} - 1 \right) k^t$$

Equation (7) shows that:

(8) $\qquad \dfrac{H_{ijt}}{h_{ijt}^m} = \dfrac{H_{ij0}}{h_{i0}} \equiv 1 + \lambda_{ij}$

where $\lambda_{ij} \geq 0$ designates the job-specific learning (from others) potential, which is independent of tenure. After simple manipulations, we get for $t \geq 1$:

(9) $\qquad R_{ijt} = g + \dfrac{n}{1+n} \left(\dfrac{\lambda_{ij} k^{t-1}}{1 + \lambda_{ij} \left(1 - k^{t-1}\right)} \right)$

This equation highlights that one part of the returns to tenure is firm dependent[4]. A worker benefits from the firm which employs her, in addition to what she gets from experience, insofar she can learn something from other workers in her job category. This prediction of the model extends one part of the dual theory story that tells that the returns to tenure are nil in secondary-type jobs, in which practically no human capital accumulation takes place, while they are positive in primary-type jobs (Dickens and Lang, 1985). Indeed, (9) indicates that the returns to tenure are minimal and reduce to *g* whenever $\lambda_{ij}=0$, *i.e.* $H_{ij0}=h_{i0}$, that is when there is no scope for learning from others on-the-job. Moreover, in the present model, the crucial distinction between primary-type jobs and secondary-type jobs does not bear on their respective levels of human capital but on the *relative knowledge* of the firm from the standpoint of each worker. The latter is obviously idiosyncratic, depending upon the tasks to be performed and personal abilities.

The marginal returns to tenure are shown by equation (9) to be a concave increasing function of the job-specific learning potential:

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[4] We avoid to say here that returns to tenure are firm-specific because what we have to say is entirely consistent with general training.

$$\frac{\partial R_{ijt}}{\partial \lambda_{ij}} > 0 \qquad\qquad \frac{\partial^2 R_{ijt}}{\partial \lambda_{ij}^2} < 0$$

It is also straightforward to show that (9) exhibits a convex decreasing relation of the marginal return to tenure with tenure:

$$\frac{\partial R_{ijt}}{\partial t} < 0 \qquad\qquad \frac{\partial^2 R_{ijt}}{\partial t^2} > 0$$

The quadratic earnings function implies a linearly decreasing curve. Thus, it is not supported by what seems a reasonable description of informal learning processes at work on-the-job. Mincer (1974) remarked that a Gompertz curve might yield a better fit than the simple quadratic function. More recently, Murphy and Welch (1990) noticed that the quadratic curve underestimates the marginal return to tenure at low and very high values of tenure, and they recommended a quartic earnings function. The steep decline of R_{ijt} with tenure is responsible for the alternating sign of $\dfrac{\partial R_{ijt}}{\partial n}$: initially positive at low values of tenure (including $t=1$), and eventually negative. Increasing the efficiency of learning on-the-job will benefit low-tenured workers who will learn faster, but it will reduce what remains to be learned from others in the future.

Finally, it can be shown that:

$$\frac{\partial R_{ijt}}{\partial g} \geq 1, \text{ for } t \geq 2 \text{ and } \lambda_{ij} \geq 0 \ \left(=1 \text{ if } \lambda_{ij} = 0\right)$$

Increasing the efficiency of experience initially increases the self-learning effect but this will provoke a multiplier effect in subsequent periods by raising the firm's knowledge.

III.   DATA AND ECONOMETRIC SPECIFICATION

A.   The data

We use in this paper a unique French survey with matched employer-employee data, the 1992 INSEE survey on labor cost and wages structure. The latter contains information about 150 000 workers across 16 000 establishments.

This survey of labor costs is carried out concurrently in all European Union countries every four years, and aims to provide comparable labor market statistics across EU countries. For the 1992 wave of this survey, INSEE matched the data with those on the structure of wages (as the subject matter of the two surveys was obviously similar). The population covered by these data is very broad, including establishments of all sizes and of all industries (which rules out agriculture, fisheries, non-traded services, central and local government).

For the regression analysis, we constructed a certain number of variables. These include the total number of years of education, total potential experience in the labor market (age – number of years of education – six), hourly earnings (gross salary plus payments in kind, all divided by the number of paid hours over the year), and the average number of paid hours of training per worker in the establishment (the weighted average of the number of hours of paid training by worker by occupational category (executive or non-executive) divided by the total number of workers by occupational category).

As for the education variable, since available information was the highest paper certificate held by the worker, we had to determine the theoretical number of years of education per worker. To do this, we calculated the median number of years of education (which is less sensitive to outliers) for each qualification considered, using a sub-sample of more than 8 000 workers from the same survey for whom the number of years of education was available. This indirect method for calculating the length of education has the advantage of partially removing the endogeneity of the education variable.

Table 1 summarizes the acronyms and definitions of the main variables used in the empirical analysis, and provides descriptive statistics.

Table 1: Descriptive statistics

Symbol	Definition	Mean	Min	Max	Standard Deviation
h_{ijt}	Hourly earnings	69.48	29.00	395.83	39.49
$hours_i$	Number of hours paid work per year	1671.78	33	2310	585.46
sex_i	1 for men. 0 for women	0.60			
age_i	Age	37.68	16	65	10.30
nat_i	1 if French. 0 otherwise	0.93			
mar_i	1 if married. 0 otherwise	0.61			
$cont_i$	1 if open-ended contract, 0 otherwise or no answer	0.86			
$exec_i$	1 if executive. 0 otherwise	0.11			
s_i	Number of years of schooling	12.77	8	18	1.65
x_i	Number of years of labor market experience (outside of the current establishment)	9.27	0	49	8.72
t_{ij}	Number of years of tenure	9.27	0	46	8.84
N	Number of observations	137 211			
S_j	Highest level of education among workers of the same establishment	14.26	10	18	1.92
X_j	Highest level of former experience among workers of the same establishment	26.88	0	49	9.34
T_j	Highest level of tenure among workers of the same establishment	16.58	0	46	10.32
reg_j	1 if Paris. 0 otherwise	0.16			
$size_j$	Size of the establishment	140.16			540.46
$union_j$	1 if trade union representatives reported in the establishment, 0 otherwise	0.25			
$eval_j$	1 if individual productivity evaluation procedures reported in the establishment, 0 otherwise	0.20			
$coop_j$	1 if cooperation among workers reported, 0 otherwise	0.49			
$shift_j$	1 if workers shifting to other jobs in the establishment reported, 0 otherwise	0.16			
$wagind_j$	1 if wage increases reported as being mainly individualized, 0 otherwise	0.20			
$twagind_j$	1 if tenure reported as being very important for setting the individualized wage increase, 0 otherwise	0.06			
$pwagind_j$	1 if worker's productivity gains reported as being very important for setting the individualized wage increase, 0 otherwise	0.35			
$trwagind_j$	1 if worker's training efforts reported as being very important in setting the individualized wage increase, 0 otherwise	0.08			
$expwagind_j$	1 worker's experience reported as being very important in setting the individualized wage increase, 0 otherwise	0.16			
$fortrain_j$	Average annual hours of paid formal training per worker in the establishment	11.83	0	1748.37	53.73
J	Number of establishments	14 693			

B.   Econometric specification

For the purpose of econometric estimation, we report (7) into (6) and take natural logarithms. If *g* is small, we get:

$$(10) \quad \log h_{ijt} = \log h_{i0} + gt + \log\left[1 + \lambda_{ij}\left(1 - k^t\right)\right]$$

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The logarithm of gross earnings is simply the sum of a linear-in-tenure Mincerian earnings function and a correction factor. The latter describes the share of her job-specific learning potential captured by an individual after t periods of tenure. If what can be learned on-the-job in any given firm is but a small share of the worker's initial stock of human capital, (10) can be further simplified and approximated by:

$$(11) \qquad \log h_{ijt} = \log h_{i0} + gt + \lambda_{ij}(1 - k^t)$$

Equation (11) further specifies the human capital earnings function by saying that each worker learns informally on-the-job both by herself and by watching others. These two effects can be identified. In the present paper, we shall use *the same* Mincerian earnings function, quadratic in experience and tenure, to estimate respectively the gross earnings (in logs) of worker i on entering the establishment j (hence, with zero tenure) h_{i0}, and of her most qualified teacher in the same establishment at that time H_{ij0}:

$$(12) \qquad \log H_{ij0}(S_{ij}, X_{ij}, T_{ij}) = a_0 + a_1 S_{ij} + a_2 X_{ij} + a_3 X_{ij}^2 + a_4 T_{ij} + a_5 T_{ij}^2,$$

with $a_1, a_2, a_4 > 0$ and $a_3, a_5 < 0$, and

$$(13) \qquad \log h_{i0}(s_i, x_i, t_{ij} \equiv 0) = a_0 + a_1 s_i + a_2 x_i + a_3 x_i^2$$

where $z_{ij} \equiv (s_i, x_i, t_{ij})$ and $Z_{ij} \equiv (S_{ij}, X_{ij}, T_{ij})$ denote the human capital vectors of i and her most qualified teacher in establishment j. The latter specification assumes that the firm's job-specific knowledge can be approximately attributed to a fictitious worker endowed with S_{ij} years of education, X_{ij} years of experience in other firms, and T_{ij} periods of tenure in the incumbent firm j, such that: $S_{ij} \geq s_i$, $X_{ij} \geq x_{ij}$, $T_{ij} \geq 0$. This is the most qualified teacher of i in her job category.

The teacher's characteristics are unobservable in our data[5], but we do observe the same variables on a random sample of employees from the same establishment. Since individuals can only learn from more qualified workers in the same job category, a minimal

assumption for recovering the unknown characteristics of worker i's teacher on-the-job is to assume that they lie between the establishment's maximum and individual values of the latter at some fixed relative position, then approximate the true maximum by the sample's maximum. Letting $Z_j = \sup_{i \in j} z_{ij}$ be the maximum observable value for the characteristic z in the establishment's sample, we write:

$$(14) \quad Z_{ij} = \beta_z Z_j + (1 - \beta_z) z_{ij} \quad \text{with} \quad 0 \leq \beta_z \leq 1$$

β_z indicates the relative distance which separates the average worker from her most qualified teacher. It takes a value of zero if there is no opportunity for learning and one if the most qualified teacher always coincides with the most qualified teacher of the establishment's sample. In order to specify the earnings function (10), we first derive the job-specific learning potential from (8) by making use of expressions (12) and (13) for H_{ij0} and h_{i0} respectively and reporting (14) into (12). When the learning potential is small, we can simplify this expression into:

$$(15) \quad \lambda_{ij} \cong \log \frac{H_{ij0}}{h_{i0}} = a_1 \beta_s \left(S_j - s_i \right) + a_2 \beta_x \left(X_j - x_i \right) + a_3 \beta_x^2 \left(X_j - x_i \right)^2$$
$$+ 2 a_3 \beta_x \left(X_j - x_i \right) x_i + a_4 \beta_t T_j + a_5 \beta_t^2 T_j^2$$

Reporting (13) and (15) into (11), we then obtain for individual i in establishment j a non-linear gross earnings equation, to which we add an error term u_{ijt}:

$$
\begin{aligned}
(16) \quad \log h_{ijt} = {} & a_0 + a_1 s_i + a_2 x_i + a_3 x_i^2 + g t_{ij} \\
& + \left(\begin{array}{l} a_1 \beta_s \left(S_j - s_i \right) + a_2 \beta_x \left(X_j - x_i \right) + a_3 \beta_x^2 \left(X_j - x_i \right)^2 \\ + 2 a_3 \beta_x \left(X_j - x_i \right) x_i + a_4 \beta_t T_j + a_5 \beta_t^2 T_j^2 \end{array} \right) \left(1 - \left(\frac{1 + g(1 + n)}{(1 + g)(1 + n)} \right)^{t_{ij}} \right) \\
& + \sum_k \delta_k c_{ijk} + u_{ijt}
\end{aligned}
$$

where c_{ijk} is a column vector of control variables and δ_k is a row vector of coefficients associated with each of these variables. We estimate (16) using non-linear least squares (NLSQ). However, since we cannot be sure that the magnitude of the learning potential is

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[5] Such observation would require a description of student-teacher interactions within establishments.

small enough for this approximation to be valid, we also estimated the exact formula (not reported here).

With cross-section data and a non-linear model, we cannot account for unobserved individual or firm heterogeneity in the manner of Abowd, Kramarz, Margolis and Troske (2000). Besides, the large number of establishments in our data set rules out the possibility of controlling for firm heterogeneity by introducing a dummy variable for each establishment into equation (16). In order to temper the effects of unobserved individual and firm heterogeneity which might bias the estimated coefficients, we added a large number of control variables to our regression[6]. We checked that the latter capture a good deal of the establishment heterogeneity by estimating the quadratic-in-tenure earnings function, which is linear in its parameters, both with establishment fixed effects (without the controls) and with the controls only. The comparison of the marginal returns to education, former experience and tenure exhibited little difference between these two estimates. By adding the sample's maximum values of education, former experience and tenure in the Mincerian equation-since they are included in the non-linear model-, these differences were further reduced (results not shown).

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[6] The control variables are: log hours and dummies for sex (women), occupation (non-executives) and region (all regions with the exception of Paris and its suburbs), three dummies for nationality (French), five dummies for marital status (married), three dummies for labor contract (open-ended contract), one dummy for the presence of trade union representatives in the establishment (no), three dummies for the presence of individual productivity evaluation procedures in the establishment (yes), four dummies for the presence of incentives for cooperation among co-workers, three dummies for the presence of systematic job turnover among workers of the establishment (no), five dummies for the degree to which wage increases are being individualized (little), five dummies for the importance of tenure for setting the individualized wage increase (none), five dummies for the importance of worker's productivity gains for setting the individualized wage increase (very high), five dummies for the importance of worker's training efforts for setting the individualized wage increase (average), five dummies for the importance of worker's experience for setting the individualized wage increase (average), four dummies for average number of paid hours of formal training in the establishment over the past year (no hours of training), twelve industry dummies (traded services) and six establishment size dummies (less than 20 workers).

IV.   RESULTS

A.   Gross Earnings Functions

Table 2 presents the estimated parameters of the gross earnings function, in column 5, along with four other models of earnings. Three versions of the Mincerian model appear in the first three columns of the table: linear in tenure (column 1), quadratic in tenure (column 2), and quartic in tenure (column 3). Moreover, the pure learning-by-watching model (LBW) is shown in column 4. All of the estimated Mincerian equations are linear in education and quadratic in former experience. The adjusted R^2 is equal to 60.41% for our model. All of the main explanatory variables are significant at the one percent level in all equations. Among the Mincerian earnings functions, we confirm on the present data that the quartic function of tenure yields a better fit than the usual quadratic and the linear equation. Moreover, the function that incorporates learning from self and others (LSO, in column 5) clearly has a better fit than the two nested models of column 1 ($n=0$) or column 4 ($g=0$). Finally, the simpler version of LSO described by (16) has been estimated in column (6). The approximation is shown to be valid since the structural parameters reported in columns (5) and (6) are remarkably similar.

The omission of self-learning leads to a severe underestimation of the knowledge diffusion parameter, since n goes from 45.22% in column 5 to 5.75% in column 4. It is more intuitive to compare the time required for a worker to learn α % of the firm's knowledge as far as she is concerned. This is easily derived from (6) and (7):

$$\left(\frac{1+g(1+n)}{1+n}\right)^t = \frac{H_t - h_t}{H_0 - h_0} = 1 - \alpha$$

after solving for t. The results of these computations are given in table 3 for the two values $\alpha=50\%$ and $\alpha=95\%$. There is a huge difference between the two models and the estimations yielded by the earnings function which incorporates both self-learning and learning-by-watching make a lot more sense. On average, it takes 1.93 years for a worker to embody 50% of the most she can learn from her establishment, and 8.37 years to embody 95% of this total. Moreover, the average worker of our sample, who has 9.27 years of tenure, has already learned 96% of what she can learn from others. The omission of self-learning greatly

Table 2: Gross earnings functions (Dependent variable: log of hourly earnings)[7]

Parameters	(1) Linear in t	(2) Quadratic in t	(3) Quartic in t	(4) LBW[1]	(5) LSO[2]	(6) LSO[2]
Coef. of s_i	0.05293^a (0.00052)	0.05283^a (0.00052)	0.05260^a (0.00052)	0.05841^a (0.00056)	0.06060^a (0.00058)	0.06055^a (0.00058)
Coef. of x_i	0.01031^a (0.00026)	0.01013^a (0.00026)	0.01024^a (0.00026)	0,01635^a (0.00056)	0.01352^a (0.00033)	0.01357^a (0.00033)
Coef. of x_i^2	-0.00021^a (8.40^e-06)	-0.00020^a (8.39^e-06)	-0.00021^a (8.38^e-06)	-0.00034^a (0.00001)	-0.00027^a (9.69^e-06)	-0.00027^a (9.69^e-06)
Coef. of t_{ij}		0.01992^a (0.00028)	0.03912^a (0.00096)			
Coef. of t_{ij}^2		-0.00022^a (9.27^e-06)	-0.00243^a (0.00011)			
Coef. of t_{ij}^3			0.00008^a (5.13^e-06)			
Coef. of t_{ij}^4			-9.70^e-07^a (7.18^e-08)			
β_s				0.38352^a (0.01298)	0.26172^a (0.00805)	0.26176^a (0.00808)
β_x				0.95666^a (0.02101)	0.21489^a (0.01202)	0.21862^a (0.01207)
Coef. of T_{ij}				0.02142^a (0,00056)	0.00377^a (0.00030)	0.00377^a (0.00029)
Coef. of T_{ij}^2				-0.00036^a (0.00001)	-0.00007^a (6.92^e-06)	-0.00007^a (6.92^e-06)
n				0.05755^a (0.00197)	0.45220^a (0.03822)	0.46631^a (0.03826)
g	0.01344^a (0.00010)				0.01077^a (0.00018)	0.01074^a (0.00018)
Constant	3.08839^a (0.01210)	3.10714^a (0.01209)	3.12898^a (0.01211)	3.00232^a (0.01249)	3.00543^a (0.01256)	3.00580^a (0.01256)
Adjusted R^2	0.5888	0.6004	0.6018	0.6021	0.6041	0.6041
N	137 211	137 211	137 211	137 211	137 211	137 211

Notes: 1: LBW= Learning by watching

2: LSO= Learning from Self and Others

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[7] For tables 2 to 7, standard errors are in parentheses and a, b and c mean respectively statistically significant at the 1%, 5% and 10% levels.

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underestimates the speed with which individuals learn from others, as we have just seen; but, on the other hand, it greatly overestimates the potential for learning from others.

Table 3 reports that a worker can learn 10% of her initial human capital on average from one establishment, while the estimate derived from the LBW model is 45%. Table 2 also indicates that the relative distance which separates the average worker from her most qualified teacher (β_z) is equal to 0.26 in terms of educational capital and 0.21 in terms of former experience capital. These two values are well inside the [0,1] interval and considerably lower than their LBW counterparts. β_s declines from 0.38 to 0.26, and β_x from 0.95 to 0.21 between columns 4 and 5 in table 2. The omission of self-learning has the mechanical effect of raising the estimated value of H_{ij0}/h_{i0}, hence of the β parameters.

Table 3: Knowledge diffusion and relative knowledge

	n **(%)**	$t_{0.50}$	$t_{0.95}$	H_{ij0}/h_{i0}
LSO	45.22	1.93	8.37	1.10 (0.0001)
LBW	5.75	12.38	53.53	1.45 (0.0005)

The Mincerian earnings function is a convenient tool for estimating the average returns to education and market experience. The return to education is then simply given by the coefficient of the length of schooling. The estimates drawn from the quadratic model are reported in table 4 and compared with those from the LSO equation in table 2. The marginal return to education (computed at the average length of schooling in the sample) is only 4.61% instead of 5.28% for the Mincerian model. Moreover, it decreases with the length of education in our model because, the more education, the less can be learned from others. The fact that investments in education and learning from others are substitutes has generally been overlooked in previous studies which emphasized the complementarity of education and self-learning[8]. In contrast, these two effects are present here.

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[8] The more educated workers receive more formal training (*eg.* Destré, Lévy-Garboua and Sollogoub 1999) and learn more by themselves informally (see eq. (1)). However, when we tested the hypothesis that education increase the individual's ability to learn *from others* on-the-job *n*, but could not find any significant positive effect.

Table 4: Marginal returns to education and former experience

	Mincerian **Quadratic in *t***	**LSO**
$\dfrac{\partial \log h_{ijt}}{\partial s_i}$	5.28	4.61
$\dfrac{\partial \log h_{ijt}}{\partial x_i}$	0.62	0.73

B. Firm's knowledge and the returns to tenure

Table 5 and Figure 1 show the schedule of gross marginal rates of return to tenure which derives from the present model of on-the-job learning (computed from equation (9)) and compare the latter with estimates drawn from two Mincerian earnings functions (quadratic and quartic in tenure).

The marginal rate of return, computed for the sample's mean tenure, is equal to 1.22%, which is significantly positive and greater than the constant rate of return to self-learning on-the-job[9], $g=1.07\%$. The difference of 0.15% measures the average increase which can be attributed to learning-by-watching. Thus nearly 12% of what is learned informally on-the-job emanates from others and 88% is the result of self-learning. However, the respective shares of these two kinds of learning are very unequally distributed over time. While the rate of return from self-learning remains constant, the benefits from imitating others are mainly reaped by workers shortly after being hired and they are very large then. For instance, table 5 shows that earnings rise by 4.50% in the first year of tenure and only 1.78% in the fifth year. Learning-by-watching accounts for three-quarters of the marginal rate of return in the first year, but this proportion falls to 49% in the fifth year and so on. The rate of return estimated by the present model is significantly higher (by a *t*-test of Student) than what is predicted by the quadratic earnings function both at low and very high tenure. Figure 1 shows that a quartic function of tenure fits our model fairly well as long as tenure does not exceed 30 years or so. However, the rates of return predicted by the LSO equation are slightly higher than the quartic in the first two years but decline more sharply.

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[9] This parameter should mainly capture returns to informal training since we control for the average number of hours of formal training in the establishment over the last year by occupational group (in two broad categories).

Table 5: Schedule of marginal rates of return to tenure (%) for selected years of tenure[10]

Model	Mincerian Quadratic in t	Mincerian Quartic in t	LSO
First year of tenure	1.98	3.74	4.50[a] (0.0046)
Second year of tenure	1.94	3.29	3.35[a] (0.0030)
Third year of tenure	1.89	2.88	2.60[a] (0.0019)
Fourth year of tenure	1.84	2.52	2.11[a] (0.0013)
Fifth year of tenure	1.80	2.21	1.78[a] (0.0009)
Mean tenure	1.61	1.32	1.22[a] (0.0001)

Figure 1: Schedules of marginal rates of return to tenure for three earnings functions

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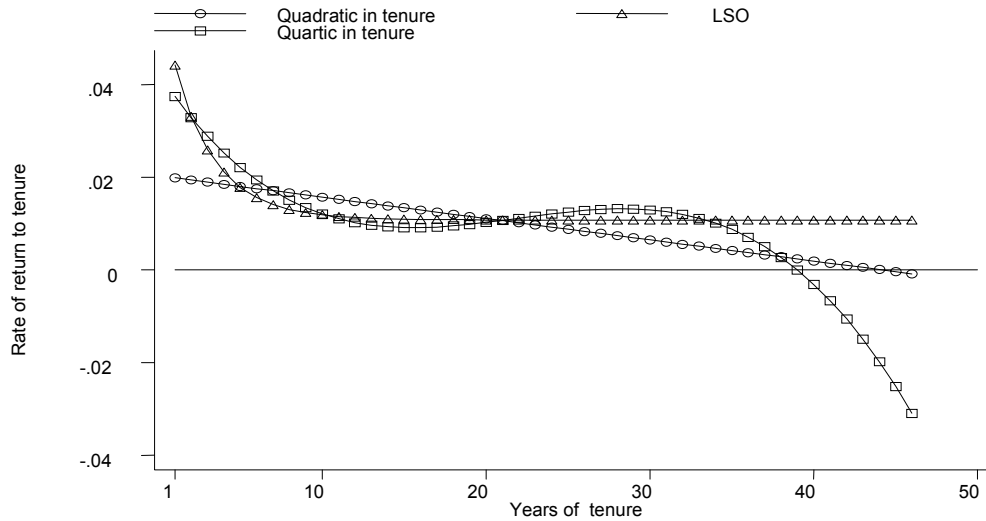
[10] For tables 5 to 7, the number of observations is 119 667 since the returns to tenure are only defined for $t \geq 1$.

C. Matching workers with jobs and firms

The present model of on-the-job learning in combination with the matched employer-employee data that we use enables us to compute the individual-specific relative knowledge of the establishment. Although the average relative knowledge of firms, H_{ij0}/h_{i0}, is estimated to be 1.10 (see Table 3), which is significantly different from one (by a t-test), there is substantial heterogeneity between jobs and firms. The distribution of relative knowledge has a mode at 1.0512 and a median which is very close to the mean around 1.10. Mainly for illustration purposes, *jobs* with a low potential for learning will be defined as those offering no more than the modal opportunities for learning on-the-job, *i.e.* $\lambda_{ij} \leq 1.0512$. Since little can be learned on these jobs, the schedule of marginal rates of return to tenure must be low, and so effective tenure must be low as well. The description of jobs having a low potential for learning is somewhat similar to that of jobs belonging to the "secondary sector" of the dual theory of labor (Doeringer and Piore 1971, Dickens and Lang 1985). By contrast, all other jobs are similar to jobs of the "primary sector". Table 6 shows the average and marginal returns to tenure (calculated in the mean point of tenure, see table 1), relative knowledge and effective tenure in jobs of the secondary and primary types. The average rate of return is given for a five-years tenure which fits the observed durations in both types of job. The average worker in primary jobs can learn 12% of her initial human capital and has 11.51 years of tenure while the average worker in secondary jobs can only learn 3% and only has 5.44 years of tenure. Thus tenure is considerably lower in secondary type-jobs than in primary-type jobs and the difference is found highly significant by a t-test. The correlations between firm's relative knowledge and tenure, or primary type-job (a dummy) and tenure, are both positive and highly significant (by a t-test) with values of 0.382 and 0.246 respectively. The potential for learning is definitely a major determinant of job stability and this conclusion does not depend on the knowledge being firm-specific as commonly assumed by human capital theory (Becker 1964; but see Rosen 1972). The average rate of return to tenure at five years is also markedly lower (by a t-test) in secondary-type jobs, *i.e.* 8.14% versus 14.50%. Finally, the difference in marginal rates of return R_{ijt} in the primary and secondary-type jobs is positive by a difference t-test. Job competition is expected to equalize the marginal rates of return between jobs, while job rationing in the primary sector would cause marginal rates of returns to be higher in the rationed segment of the job market. Column 3 compares the marginal returns to tenure in the primary-type and secondary-type jobs (computed at the average tenure

of sector). Secondary jobs do not appear less profitable than primary jobs on the margin. Therefore, our results do not support the job rationing hypothesis of dual labor market.

Table 6: Returns to tenure (%) and the dual labor market accross jobs
at the individual job's level

	$\overline{R}_{ij5}$	$R_{ij}(\bar{t})$	$R_{ij}(\bar{t}_s)$ $s = 1,2$	H_{ij0}/h_{i0}	t_{ij}
Secondary jobs	8.14[a] (0.0071)	1.13[a] (0.0001)	1.28[a] (5.62[e]-04)	1.03 (0.0001)	5.44 (0.0393)
Primary jobs	14.50[a] (0.0103)	1.24[a] (0.0001)	1.14[a] (7.15[e]-05)	1.12 (0.0001)	11.51 (0.0276)
Total	13.58[a] (0.0109)	1.22[a] (0.0001)	-	1.10 (0.0001)	10.63 (0.0250)

The foregoing analysis applies to jobs, that is to specific employer-employee matches. Do the same conclusions hold when jobs are aggregated at the establishment level? This question deserves to be raised because the dual theory of labor was originally set at the firm's level (Doeringer and Piore 1971) and disaggregated data are often lacking below the firm's or establishment's level. Therefore we now calculate the mean relative knowledge on the sample of workers in each establishment and draw the frequency distribution of this mean across establishments. The mode of this new distribution is 1.0710 while the mean and median are around 1.08. *Firms* with a low potential for learning on average will be defined as those for which the mean relative knowledge does not exceed 1.0710, and will be said to form the "secondary sector". Table 7 extends the information displayed by table 6 at the establishment's level, and exactly the same conclusions can be reached. However, when we have a closer look at the employer-employee matches, the picture is partly modified by the aggregation. While education has a significantly negative (by a *t*-test) correlation (-0.293) with firm's relative knowledge at the job's level, the correlation turns significantly positive (by a *t*-test) and small (0.031) at the establishment's level. The rationale behind this surprising result is that more educated individuals choose firms offering greater opportunities for learning because they are willing to invest more in training; but, since they know more, they eventually have less to learn from others. Moreover, the aggregation greatly magnifies the positive correlation of the potential for learning (measured by relative knowledge) with

observed earnings: it rises from -0.016 to 0.173 (statistically significant by a *t*-test). Thus predictions of the dual theory of labor regarding the employer-employee match which are visible at the establishment's level seem to vanish at the individual job's level. Other implications of dual labor theory are also captured by our simple typology of sectors. For instance, 50% of workers employed in primary-type jobs versus only 14% of workers in secondary-type jobs belong to establishments which have trade union representatives. Besides, 33% of primary-type establishments have trade union representatives versus 12% of secondary-type establishments.

Table 7: Returns to tenure (%) and the dual labor market accross jobs

at the establishment's level

	Mean $\overline{R}_{ij5}$ by establishment	Mean $R_{ij}(\bar{t})$ by establishment	Mean $R_{ij}(\bar{t}_s)$ $s=1,2$ by establishment	Mean (H_{ij0}/h_{i0}) by establishment	Mean (t_{ij}) by establishment
Secondary sector	9.06[a] (0.0162)	1.63[a] (0.0055)	1,24[a] (8.34[e]-04)	1.04 (0.0002)	6.54 (0.0721)
Primary sector	13.61[a] (0.0233)	1.85[a] (0.0068)	1,17[a] (2.80[e]-04)	1.11 (0.0003)	10.64 (0.0552)
Total	11.88[a] (0,0241)	1.76[a] (0.0048)	-	1.08 (0.0003)	9.08 (0.0468)

IV. SUMMARY AND CONCLUSIONS

We have suggested a simple model of informal learning on-the-job which combines self-learning and learning from others. This yields a closed-form solution that revises the Mincer-Jovanovic's (1981) treatment of tenure in the human capital earnings function by relating earnings to the individual's job-specific learning potential. We estimated the structural parameters of this non-linear model on a large French survey with matched employer-employee data. We find that workers on average can learn from others ten percent of their own human capital on entering the firm, and catch half of their learning potential in

just two years. Since individuals learn fast from their co-workers, the estimated returns to tenure loom larger than predicted by a quadratic, or even a quartic-in-tenure, Mincerian function in the first years and decline more sharply (until about thirty years). Learning by watching accounts for three quarters of the marginal rate of return in the first year of tenure, but this share falls rapidly, with an average of 12%. While education and self-learning on-the-job are complementary, education and learning from others on-the-job are substitutes. The more education, the less can be learned from others. This forces the marginal return curve to decline slightly with education, an effect which was not captured by current theory. The measurement of workers' job-specific learning potential provides a simple and novel characterization of primary-type and secondary-type jobs and establishments. With the latter, it is possible to revisit the dual labor market theory. We find a strong relationship between the job-specific learning potential and tenure. We suggest that the opportunity of learning much from co-workers is an essential feature of primary-type jobs and firms. However, a closer look at data shows, with this definition at least, that primary-type jobs are not rationed. Furthermore, predictions of the dual labor theory regarding the positive match of primary-type firms (which offer high learning opportunities) with highly endowed workers (educated, high wages) are visible at the establishment's level but seem to vanish at the job's level.

The LSO (Learning from Self and Others) earnings function estimated here is non-linear and thus could not be estimated by a standard OLS regression. However, it might be linearized for the ease of estimation, if one is not interested in recovering the structural parameters, by means of a Taylor expansion of its non-linear part at the second, or a higher, order. Future research may also adopt more convenient specifications for the job-specific learning potential and this is certainly an area where important progress can be made. Our paper can be seen as a preliminary attempt to adapt the Mincerian earnings function to matched employer-employee data.

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