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On the industry experience premium and labor mobility

Montserrat Vilalta-Bufi¹

Adreça correspondència :

Departament de Teoria Econòmica and CAEPS,
Universitat de Barcelona,
Avda. Diagonal, 690,
08034 Barcelona, Spain.
Tel: +34 934020107.
Fax: +34 934039082.
Contact: montsevilalta@ub.edu

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Abstract:

There is evidence that experience premium differs across industries. We propose a theoretical model for explaining these differences. We assume that labor mobility brings external knowledge to the firm, which increases its productivity. We find that industry experience premium is decreasing in the inter-firm mobility costs, while increasing in the learning-by-doing and the technological level of the industry. Moreover, it has a U-shape relationship with the level of learning-by-hiring, the substitutability between different types of experienced workers and the variety of knowledge in the industry. Results are consistent with the empirical findings that R&D-intensive industries have steeper wage profiles.

JEL Classification: J24; J31; J61

Keywords: labor mobility, industry experience premium, wage growth, learning-by-hiring.

Resum:

Hi ha evidència que l'experiència es remunera diferentment segons la indústria. Proposem un model teòric que explica aquestes diferències. Suposem que la mobilitat de treballadors aporta coneixement extern a l'empresa i això augmenta la seva productivitat. Els resultats mostren que l'experiència és millor remunerada en les indústries amb costos de mobilitat baixos, amb molt aprenentatge (learning-by-doing) i alt nivell tecnològic. A més, trobem una relació en forma de U entre la remuneració de l'experiència i el nivell d'absorció de coneixement extern, la substitutibilitat entre diferents tipus de treballadors i la varietat de coneixement dins la indústria. Els resultats són consistents amb l'evidència que les indústries intensives en I&D remuneren millor l'experiència.

1. Introduction

There is evidence that experience premium differs across industries. There are two open controversies related to this evidence. The first controversy is about which economic theory prevails in explaining wage growth. The second controversy refers to the empirical relevance of firm, industry and general experience on wage growth. This paper adds to this literature by proposing a theoretical explanation for these inter-industry differences in experience premium. In our model, the level of labor mobility across firms influences the experience premium. Consequently, the determinants of labor mobility affect also the experience premium of the industry.

Regarding the first controversy, there are three main theories that explain wage growth.¹ According to the *human capital theory*, the wage growth is explained by worker's productivity growth, through training or learning-by-doing (Becker 1962; Altonji and Shakotko 1987). Industries which offer more training should provide a steeper wage profile according to this theory. Moreover, human capital theory predicts that firm-specific training leads to both, a steeper wage profile and lower labor mobility. (Lazear 1981) proposes a second theory, the *delayed compensation theory*. He argues that firms postpone part of the payment to motivate workers to work hard in the first period. In this case, we would observe steeper profiles in those industries where worker's effort is less observable. Third, and within the *matching theory*, incomplete information on worker's productivity may explain why wages grow with tenure (Jovanovic 1979). In this case, wage growth is purely a result of the quality of matching. All of these theories predict that workers who are offered a steeper wage profile should be less likely to leave the firm. We add an alternative theory to this controversy. Although our paper conforms with the human capital theory, since

¹ For some examples of papers testing these theories see Abraham, K. G. and H. S. Farber (1987), Altonji, J. G. and R. A. Shakotko (1987), Brown, J. N. and G. S. Becker (1989), Barth, E. (1997).

wage growth comes from an increase in worker's productivity, we propose a model where it is compatible to have a steep wage profile and a high level of labor mobility. Our results are consistent with the evidence found in (Levine 1993) that establishments with high returns to tenure do not have low levels of labor turnover.

The second controversy is about the empirical relevance of firm, industry and general experience on wage growth. There is a handful of empirical studies showing that differences in returns to industry tenure exist. (Neal 1995) and (Parent 2000) give evidence that workers receive compensation for industry-specific skills instead of firm-specific skills. According to their results, worker's experience in an industry and not firm tenure matters for the wage profile. Using German data (Dustmann and Meghir 2005) find that returns to industry tenure are 1% per year for skilled workers and zero for the unskilled. They also find, however, that general experience pays substantially more to skilled workers, while firm tenure provides high returns to unskilled workers. (Allen 2001) shows that wage growth varies across industries. This is the only paper we are aware of that explicitly allows for differences in wage growth across industries. One of his results is that R&D-intensive industries have steeper wage profiles than industries with little R&D activity. Our model is consistent with this result and proposes some other industry characteristics that should be taken into account when studying wage growth.

This paper makes two main contributions. First, we provide a theory on differences in wage growth across industries. New industry characteristics are introduced that had not been considered in the literature, namely learning-by-hiring, mobility costs, learning-by-doing, variety of knowledge and complementarity of experienced workers. And second, we propose an alternative way of modeling inter-firm labor mobility within the neoclassical

framework, which leads to an extended Total Factor Productivity. In particular, we obtain that the TFP depends on the technological level, the learning-by-doing and the composition of labor within the firm.

We represent an industry by a small open economy. We solve first for the industry equilibrium and then perform a comparative static analysis to get the inter-industry results. There are four main assumptions in our model. First, markets are competitive, so workers are paid their marginal productivity. Second, there is labor market segmentation in the sense that each industry has a fixed supply of labor. One may think of individuals having strong tastes on which industry to work in, or industries requiring specific workers' characteristics (Dickens and Lang 1988). Although this is a strong assumption, it allows us to model labor mobility while still having a tractable model. Third, and most importantly, it is assumed that mobility of workers within an industry induces knowledge diffusion. That is, workers have embodied knowledge and when they move between firms their knowledge travels with them. Evidence on the transfer of knowledge through labor mobility (learning-by-hiring) refers especially to the mobility of technical or R&D personnel in high-tech or R&D intensive industries (Saxenian 1994, Zucker, Darby et al. 1998, Almeida and Kogut 1999). In our model only experienced workers may have incentives to move between firms. Finally, we assume that heterogeneity of knowledge brings extra productivity to the firm. There is evidence that innovation comes easier when there is exchange of knowledge among scientists, technicians or researchers in general (Peri 2005, Leonard and Sensiper 1998, Ettlíe 1980, Sakakibara 1997). Different points of view or different expertises together may innovate faster than a homogeneous group of workers. Furthermore, the latter literature emphasizes tacit knowledge, which requires face-to-face contact among individuals. We introduce this observation in our model by assuming that workers can exchange knowledge only within the firm.

Our model gives two main predictions about the inter-industry experience premium, which had not been obtained yet from any theoretical model. First, we find that industries with either low or high learning-by-hiring, narrow or wide variety of knowledge and strong or weak complementarity between experienced workers reward better industry tenure than industries with intermediate levels of these variables. Second, we obtain that industries with lower mobility costs, larger learning-by-doing and higher technological level give a steeper wage profile to their workers.

The rest of the paper is organized as follows. Next section develops a model of an industry with labor mobility and knowledge diffusion. Section 3 describes the symmetric equilibrium. In section 4 results are presented. First, the solution for the case of zero mobility costs is computed. Afterwards, the comparative static analysis with positive mobility costs is analyzed. Section 5 concludes.

2. The model

Consider an industry represented by a small open economy. Agents can borrow or lend money at an exogenous interest rate r_t . Let F_t be the number of firms in the industry each period. Firms are identical in everything except that each of them has a different type of knowledge. Labor markets are segmented in the sense that there is a fixed supply of labor per industry.

Workers live for two periods and each generation has a measure N_t of individuals ready to work in a particular industry. When individuals are young they work in a firm as unexperienced workers. By working in the firm they learn the specific knowledge of that firm without any cost (learning-by-doing), so that, at the beginning of the next period, there is a positive amount of senior

workers with the knowledge developed in each firm. We call them experienced workers.

In each period firms may hire their own experienced workers and external experienced workers. Denote by λ_{it}^j the amount of experienced workers from firm j that are hired by firm i at period t , $j \neq i$. As already stated above, they have embodied knowledge type j . We call them poached workers. Similarly, let η_{it} be the amount of own experienced workers hired by the same firm i at period t , which have knowledge type i . We call them retained workers.

The production function of each firm is $Y_{it} = H_{it}^\alpha K_{it}^\beta (B_t L_{it})^{(1-\alpha-\beta)}$ where H_{it} is a measure of effective units of human capital, K_{it} is physical capital, B_t is a measure of the productivity level of young workers and L_{it} is the total young employment of firm i ($i = 1, \dots, F$). We define human capital as an asymmetric CES function on all types of experienced workers hired by the firm.

$$H_{it} = [(\eta_{it} A_{it})^\sigma + p \sum_{j \neq i} (\lambda_{it}^j A_{jt})^\sigma]^{1/\sigma}, \quad (1.1)$$

where A_{jt} is a measure of the knowledge of the type- j worker and p is a parameter which lies between 0 and 1 and measures the ability of *learning-by-hiring* of the firm.²

We assume that $A_{it} > B_{t-1}$, which means that workers learn while working in the firm. We refer to it as *learning-by-doing*. In contrast, *learning-by-hiring* refers to the ability of a firm to acquire external knowledge through hiring external workers (poaching). We consider it may be limited by three main factors: the intrinsic characteristics of the knowledge in question (whether it is firm or

² Notice that the asymmetry in the CES function appears because we assume that knowledge from own workers (A_{it}) is fully accessible by the firm while knowledge from poached workers may be less accessible, i.e. $p \in [0, 1]$.

industry-specific); the degree of capacity of firms to acquire such external knowledge (concept of absorptive capability of firms developed by (Cohen and Levinthal 1990)), and finally, the type of environment where firms develop their tasks (e.g. institutions, local legal system which may enforce or not clauses not-to-compete, strongly defend trade secrets, etc.).³ When one or several of these factors diminish the potential of learning-by-hiring, the parameter p will be low, and vice versa.

Knowledge in our model has two dimensions: variety and level of knowledge. The subindex i in A_{it} indicates the *type of knowledge* (in which firm the worker learned his knowledge), while the *level of knowledge* is indicated by the particular value of A_{it} . In general the level of knowledge may be different across firms. Variety of knowledge is ensured by assuming that each firm has a different type of knowledge.

With such specifications, we obtain a functional form for output similar to the one derived in (Romer 1990), but instead of different types of capital goods, we have different types of human capital. In the conventional specification, total human capital is implicitly defined as being proportional to the sum of all the types of human capital, assuming perfect substitutability among them. Instead, we allow for some level of complementarity among different types of human capital. In our case the elasticity of substitution between different types of

³ There is empirical evidence that shows how differences in legal systems influence the rate of labor mobility of a region when learning-by-hiring is relevant. Hyde, A. (1998), Gilson, R. J. (1999) and Valetta, R. (2002) argue that Silicon Valley was originated in California precisely because clauses not-to-compete have weak enforceability in that state. Almeida and Kogut (1999) point out at the importance of "social institutions that support a viable flow of ideas within the spatial confines of regional economies" for creating the externalities that foster innovation (p.916).

experienced workers is $\frac{1}{1-\sigma}$. We assume that they are imperfect substitutes, that is, $0 < \sigma < 1$.⁴ The output is given by:

$$Y_{it} = [(\eta_{it} A_{it})^\sigma + p \sum_{j \neq i} (\lambda_{it}^j A_{jt})^\sigma]^{\frac{\alpha}{\sigma}} K_{it}^\beta (B_t L_{it})^{1-\alpha-\beta}. \quad (1.2)$$

We assume decreasing returns to each input ($0 < \alpha < 1$, $0 < \beta < 1$ and $\alpha + \beta < 1$). The parameter B_t converts raw quantities of unexperienced labor into efficiency units. We assume it is the same for all firms, which means that all young workers have the same level of education when entering the industry. Notice that even though the production function has constant returns to scale, the number of firms matters because it determines the variety of knowledge in the economy. Moreover, we assume that without workers there is no access to knowledge.

Notice also that the CES functional form of the human capital measure ensures that firm productivity is increasing with the variety of knowledge. The interpretation is that exchange of knowledge matters for productivity. We allow for the interaction of knowledge to happen only when two workers work in the same firm, which is coherent with the idea that tacit knowledge is important for innovation and needs face-to-face contact to be transmitted.

We assume perfect competition in the product market in order to isolate the exchange of knowledge effect in the labor market. To simplify we assume that all firms can sell all the product at a given price, which we normalize to 1.

At the beginning of each period there is a measure $L_{i,t-1}$ of experienced workers for each type of knowledge in the industry ($i=1, \dots, F$). Moreover, there is a

⁴ Note that the production function evaluated at $\sigma=0$ is not well-defined and the Cobb-Douglas function cannot be derived.

positive cost for workers to move from one firm to the other, which we denote by m . It may include the real cost of changing the place of residence as well as the subjective cost associated to it.

We consider the case of perfect competition in the labor market, so that firms take wages as given. Let w_t^i be the wage of young workers and ω_{it} the wage of type i experienced workers paid by firm i in period t . Notice that the wage of experienced workers ω_{it} has to be greater than w_t^i to induce experienced workers to work. Otherwise they would prefer to work as unexperienced ones.

Let ω_{jt}^i be the wage paid by a firm j to the experienced workers type i . For this type of workers to move to firm j , they must be paid at least as much as in firm i plus the *mobility costs*, that is, $\omega_{jt}^i \geq \omega_{it} + m$. Since the labor market is perfectly competitive, the former condition holds with equality in equilibrium and an experienced worker is indifferent between moving or staying. In such a case we assume that workers are willing to change the firm.

Each firm i decides the amount η_{it} of own experienced workers to retain, the amount λ_{it}^j of experienced workers to poach from each firm j ($j \neq i$), the amount of young workers to hire L_{it} and the amount of physical capital K_{it} to rent. We assume full depreciation of physical capital.

The problem of the firm is to maximize the discounted sum of future profits. In our specification each period is independent from each other. In particular we assume that the technological parameters A_{it} and B_t are exogenous and do not depend on firm decisions. Then the firm's problem can be expressed as a period by period maximization.

Given the competitive wages w_t^j , ω_{jt} and ω_{it}^j such that $\omega_{it}^j \geq \omega_{jt} + m$ and $\omega_{it} \geq w_t^i$, the problem of the firm is the following:

$$\begin{aligned} \max_{\eta_{it}, \lambda_{it}^j, L_{it}, K_{it}} & ((\eta_{it} A_{it})^\sigma + p \sum_{j \neq i} (\lambda_{it}^j A_{jt})^\sigma)^{\frac{\alpha}{\sigma}} K_{it}^\beta (B_t L_{it})^{1-\alpha-\beta} - \\ & - w_t^i L_{it} - \omega_{it} \eta_{it} - \sum_{j \neq i} \omega_{it}^j \lambda_{it}^j - R_t K_{it}. \end{aligned}$$

The first order conditions for this problem are:

$$\frac{\alpha \eta_{it}^{\sigma-1} A_{it}^\sigma K_{it}^\beta (B_t L_{it})^{1-\alpha-\beta}}{((\eta_{it} A_{it})^\sigma + p \sum_{j \neq i} (\lambda_{it}^j A_{jt})^\sigma)^{\frac{\alpha}{1-\sigma}}} = \omega_{it}, \quad (1.3)$$

$$\frac{p \alpha A_{jt}^\sigma K_{it}^\beta (B_t L_{it})^{1-\alpha-\beta}}{((\eta_{it} A_{it})^\sigma + p \sum_{s \neq i} (\lambda_{it}^s A_{st})^\sigma)^{\frac{\alpha}{1-\sigma}} (\lambda_{it}^j)^{1-\sigma}} = \omega_{jt} + m \quad \forall j \neq i, \quad (1.4)$$

$$(1 - \alpha - \beta) ((\eta_{it} A_{it})^\sigma + p \sum_{j \neq i} (\lambda_{it}^j A_{jt})^\sigma)^{\frac{\alpha}{\sigma}} K_{it}^\beta B_t^{1-\alpha-\beta} L_{it}^{-\alpha-\beta} = w_t^i, \quad (1.5)$$

$$\beta ((\eta_{it} A_{it})^\sigma + p \sum_{j \neq i} (\lambda_{it}^j A_{jt})^\sigma)^{\frac{\alpha}{\sigma}} K_{it}^{\beta-1} (B_t L_{it})^{1-\alpha-\beta} = R_t. \quad (1.6)$$

Equations (3), (4) and (5) equalize marginal productivity to the marginal cost of retained workers, poached workers and young workers, respectively. Notice that we already introduce the equilibrium result on wages, $\omega_{it}^j = \omega_{jt} + m$. Similarly, equation (6) sets marginal productivity of physical capital to the marginal cost, which is the rental payment R_t . In equilibrium it must happen that the rental rate equals the interest rate plus the depreciation rate ($R_t = r_t + 1$) in order to ensure no arbitrage possibilities in the economy. Notice that since marginal productivity of poached workers at $\lambda_{it}^j = 0$ is infinity for all i, j (see equation 4)

and there is no cost of adapting variety of knowledge, all firms poach workers from all the other firms in the industry to access the whole range of knowledge.⁵ Moreover, firms always want to retain some of their own workers because the marginal productivity of retained workers when the industry retains zero workers is infinite (see equation 3).⁶

Since individual labor supply is inelastic, individuals only care about maximizing their life-time income, which depends on which firm they start working. In equilibrium it must happen that all workers within an industry have the same life-time income in present value.

$$w_{it} + \frac{\omega_{i,t+1}}{1+r_{t+1}} = w_{jt} + \frac{\omega_{j,t+1}}{1+r_{t+1}}, \quad \forall i \neq j. \quad (1.7)$$

Notice that although an experienced worker type i poached by firm j earns $\omega_{jt}^i = \omega_{it} + m$, he incurs a cost m by moving, so the total disposable income reduces to ω_{it} . Thus, equation (7) refers to both stayers and movers.

Next we present the market clearing conditions for the labor market. Equation (8) refers to the market for young workers and equation (9) to the experienced workers' market.

$$\sum_{i=1}^F L_{it} = N_t, \quad (1.8)$$

⁵ We could limit the number of firms from which to poach workers by introducing a cost of adaptation of external knowledge which increases with the variety of knowledge. This would complicate the analysis without giving any new insights into the model.

⁶ These conditions are sufficient but not necessary to obtain positive labor mobility in equilibrium. The necessary condition for positive labor mobility is that the marginal productivity of the first worker type i willing to move is lower in her firm of origin than in any other firm. Similarly, the condition for having some retained workers in equilibrium is that the marginal productivity of the first retained worker is larger than the marginal productivity of this type of worker in any other firm when all workers of his type are working for that firm.

$$\sum_{j \neq i} \lambda_{jt}^i + \eta_{it} = L_{i,t-1} \quad \forall i = 1, \dots, F. \quad (1.9)$$

In the left-hand side of equations (8) and (9) there is the total demand for young workers and experienced workers type i , respectively. The right-hand side shows the total supply of these types of workers. Equations (3) to (9) determine the equilibrium of this economy.

3. The symmetric equilibrium

In a symmetric equilibrium all levels of knowledge are the same across firms, although the type of knowledge keeps being different for each firm. In such a case $A_{it} = A_i \forall i$. We also assume that there is no population growth neither technological growth (N_t , F_t , B_t and A_t are constant overtime). Thus, hereinafter we suppress the time subscripts.

In a symmetric equilibrium all firms hire the same amount of young workers each period. This implies that there is the same amount of experienced workers of each type at the beginning of each period ($L_i = \frac{N}{F} \forall i$). Moreover, also due to symmetry, wages are the same for all types of experienced worker.

Definition 1. *Given a constant exogenous interest rate r , the symmetric equilibrium is characterized by the vector of variables (η, λ, L, K) and the prices (w, ω) that solve the following system of equations:*

$$\alpha \eta^{\sigma-1} A^\alpha K^\beta (BL)^{1-\alpha-\beta} (\eta^\sigma + p(F-1)\lambda^\sigma)^{\frac{\alpha}{\sigma}-1} = \omega, \quad (1.10)$$

$$p\alpha \lambda^{\sigma-1} A^\alpha K^\beta (BL)^{1-\alpha-\beta} (\eta^\sigma + p(F-1)\lambda^\sigma)^{\frac{\alpha}{\sigma}-1} = \omega + m, \quad (1.11)$$

$$(1-\alpha-\beta)(\eta^\sigma + p(F-1)\lambda^\sigma)^{\frac{\alpha}{\sigma}} A^\alpha K^\beta B^{1-\alpha-\beta} L^{-\alpha-\beta} = w, \quad (1.12)$$

$$\beta(\eta^\sigma + p(F-1)\lambda^\sigma)^{\frac{\alpha}{\sigma}} A^\alpha K^{\beta-1} (BL)^{1-\alpha-\beta} = r + 1, \quad (1.13)$$

$$L = \frac{N}{F}, \quad (1.14)$$

$$(F-1)\lambda + \eta = L. \quad (1.15)$$

Equations (10) to (13) come from the firm's problem and equations (14) and (15) are the labor market clearing conditions. Note that equation (7) becomes an identity in a symmetric equilibrium. We prove in the appendix that the symmetric equilibrium for this economy exists. Moreover, we show that under some conditions it is unique.

In the symmetric case we can rewrite the firm production function as:

$$Y = \left(\frac{A}{B}\right)^\alpha B^{1-\beta} \left(\left(\frac{\eta}{L_E}\right)^\sigma + p(F-1) \left(\frac{\lambda}{L_E}\right)^\sigma \right)^{\frac{\alpha}{\sigma}} L_E^\alpha K^\beta L^{1-\alpha-\beta}, \quad (1.16)$$

where L_E is the total amount of experienced workers in the firm. We obtain a standard Cobb-Douglas production function with three inputs: experienced labor (L_E), physical capital (K) and young labor (L). The non-standard result is that the total factor productivity (TFP) is composed of three elements: the learning-by-doing, the technological level and the labor composition within the firm. $\left(\frac{A}{B}\right)^\alpha$ denotes the *learning-by-doing* component of the TFP, $B^{1-\beta}$ denotes

the *technological level* and finally $\left(\left(\frac{\eta}{L_E}\right)^\sigma + p(F-1) \left(\frac{\lambda}{L_E}\right)^\sigma \right)^{\frac{\alpha}{\sigma}}$ describes the

effect of the *firm composition of experienced labor* on the TFP. Notice that when $\frac{A}{B} > 1$ there is learning-by-doing in the industry. Moreover, when A and

B grow in the same proportion, then the learning-by-doing component is not affected and the technological level increases.

We refer to the industry-specific experience premium as the real wage growth a worker experiences in his life. Using equations (10) and (12) we obtain that

$$\frac{\omega}{w} = \frac{\alpha L}{(1 - \alpha - \beta)\eta \left(1 + p(F - 1) \left(\frac{\lambda}{\eta} \right)^\sigma \right)}. \quad (1.17)$$

The previous equation reveals that all the parameters of the model affect the industry experience premium through changes in the composition of the labor force within the firm.

4. Results

Next, we analyze how industries with different levels of learning-by-hiring capabilities, different mobility costs, different learning-by-doing possibilities, and different initial productivity of workers have different experience premia. We first solve analytically for the case of zero mobility costs. Then we simulate the model with positive mobility costs and pursue a comparative static analysis on the symmetric equilibrium.

4.1 The case of zero mobility costs

It is useful to obtain the solution of the model for the case of zero mobility costs ($m=0$). In such a case, it is possible to obtain an explicit solution for the equilibrium. Using equations (10), (11) and (13)-(15) we derive an expression for λ , η and $\frac{\lambda}{\eta}$.

$$\lambda = \frac{p^{\frac{1}{1-\sigma}} N / F}{1 + (F - 1)p^{\frac{1}{1-\sigma}}}, \quad (1.18)$$

$$\eta = \frac{N / F}{1 + (F - 1)p^{\frac{1}{1-\sigma}}}, \quad (1.19)$$

$$\frac{\lambda}{\eta} = p^{\frac{1}{1-\sigma}}. \quad (1.20)$$

We can observe that in absence of mobility costs labor mobility only depends on the ability of learning-by-hiring (p), the substitutability between different types of workers (σ) and the size of the industry (N and F). Notice that technological variables (A and B) do not affect labor mobility in this case. Labor mobility is increasing with the learning-by-hiring and decreasing with the elasticity of substitution and the variety of knowledge. Obviously, with positive mobility costs, the rate of poached workers over retained workers is always lower than the value obtained in this section.

It can be proved that in the case of zero mobility costs, the equilibrium amount of labor mobility coincides with the amount of labor mobility that maximizes the human capital measure (H). In contrast, with positive mobility costs, the equilibrium labor mobility is below this level, so the human capital measure could be increased by increasing labor mobility. It would not be efficient, however, since larger labor mobility would also increase the total mobility costs.

To obtain the industry experience premium in the case of zero mobility costs, we take equation (17) and substitute η and λ by their equilibrium value (equations (18) and (19)).

$$\frac{\omega}{w} = \frac{\alpha}{1-\alpha-\beta}. \quad (1.21)$$

In the equilibrium with zero mobility costs the experience premium only depends on the input share of experienced and young workers. Positive mobility costs are therefore essential to have an impact of labor mobility on wage growth.

4.2 The comparative static analysis with mobility costs

When mobility costs are positive it is not possible to solve explicitly for the equilibrium. We resort to simulation exercises to examine the factors that determine experience premium in our model. We provide a formal proof of the results for the case $\alpha > (1 - \beta)\sigma$ in the appendix.⁷

For the simulation we take standard values of the basic parameters. We assume each period has 25 years, $\alpha = 0.4$ and $\beta = 0.3$. Since there is no previous literature for σ , we take an arbitrary value for the baseline parametrization, 0.5, which corresponds to an elasticity of substitution among different types of experienced workers of 2. We give arbitrary numbers to the rest of the parameters in order to have interior solutions: $A = 100$, $B = 1$, $N = 100$ and $F = 10$. We assume a 5% annual interest rate, which corresponds to a 240% interest rate in 25 years. Results are robust to changes in the parametrization baseline.⁸

Figures 1 and 2 show the relationships between the parameters of the model and the two main variables: labor mobility and experience premium. As expected, all the parameters that affect positively the productivity of poached workers induce larger labor mobility. The learning-by-doing, the technological level, the variety of knowledge and the learning-by-hiring are in this group. In contrast, mobility costs and the elasticity of substitution have a negative relationship with labor mobility.

⁷ We obtain the same qualitative results in all simulations, regardless of having $\alpha > (1 - \beta)\sigma$ or $\alpha < (1 - \beta)\sigma$. However, the analytical proof for the latter case is weaker since it requires additional assumptions. It is available upon request.

⁸ Simulation was run for several values of the parameters with no changes in the qualitative results. Particular attention was given to check robustness in two cases: when $\alpha > (1 - \beta)\sigma$ and $\alpha < (1 - \beta)\sigma$. Values for α , β and σ ranged from 0.2 to 0.4, from 0.1 to 0.6 and from 0.1 to 0.9, respectively.

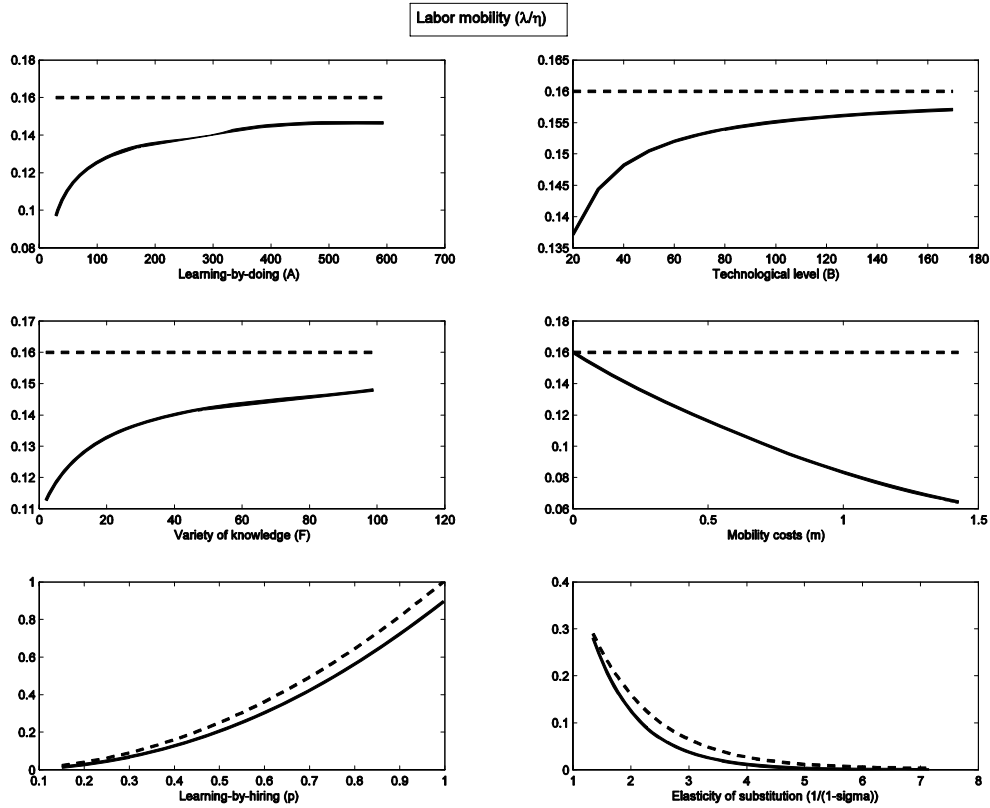


Figure 1. $\frac{\lambda}{\eta}$ as a function of the industry characteristics. Simulation results.

Dashed lines show the equilibrium with zero mobility costs.

More surprising are the results on industry experience premium. The dashed lines in figure 2 correspond to the experience premium in absence of mobility costs. The first thing to be noticed is that the experience premium with positive mobility costs is lower than the experience premium with no mobility costs. The intuition behind is that larger mobility costs reduce the total demand for experienced workers, and thus the experience premium.

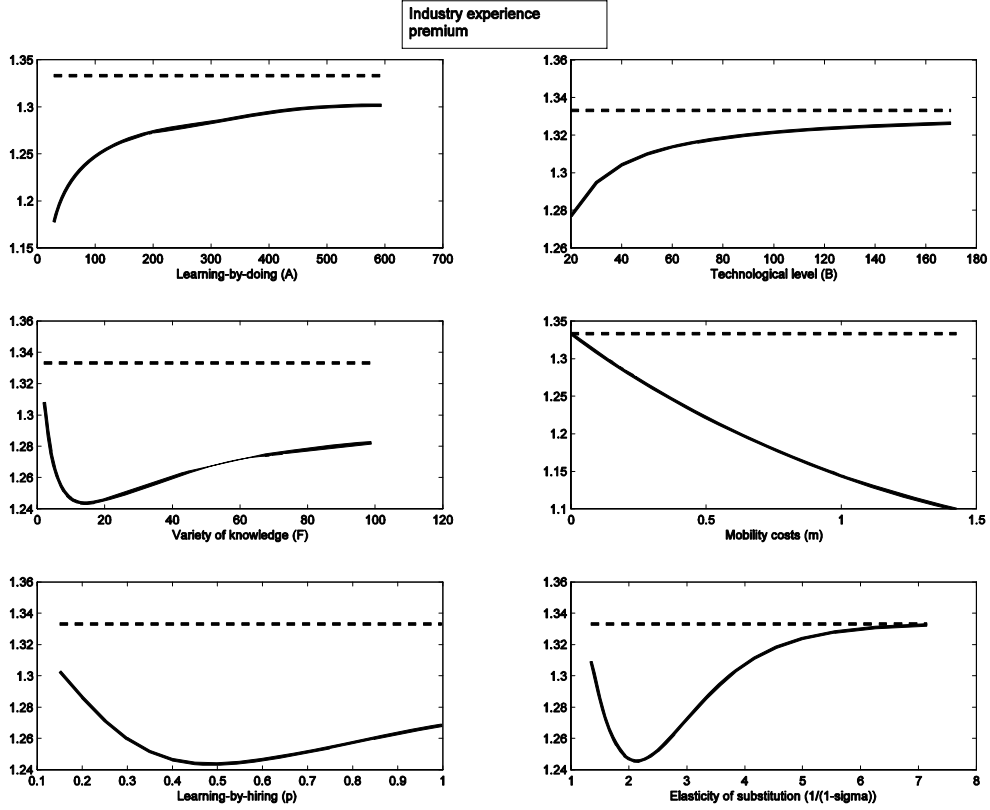


Figure 2. Experience premium ($\frac{\omega}{w}$) as a function of the industry characteristics.

Simulation results. Dashed lines show the equilibrium with zero mobility costs.

While the learning-by-doing, the technological level and the mobility costs have a monotonic relationship with the experience premium, the other parameters under study reveal a non-monotonic relationship. We observe that experience premium presents a U-shape relationship with the variety of knowledge, the learning-by-hiring and the elasticity of substitution between different types of workers.

Equation (17) reveals that most of the effects of the parameters on experience premium go through the amount of retained workers (η) and the relative amount of labor mobility ($\frac{\lambda}{\eta}$). Both channels are a measure of the mobility of workers in the industry, which is the main determinant of the industry experience premium.

An increase in the mobility of workers has two effects on the firm: a larger productivity level⁹ and a larger bill for mobility costs. This creates a trade-off on the net productivity of experienced workers. Results on experience premium depend on which of these two effects dominates.

To analyze the effect of mobility costs on experience premium recall that an increase in mobility costs reduces the amount of labor mobility. This in turn provokes a decrease in the human capital measure of the firm and an ambiguous effect on the total mobility costs bill. It turns out that the former effect dominates and the industry experience premium is decreasing in mobility costs.

The learning-by-doing and the technological level, both affect positively labor mobility. This means that an increase in these parameters translates into larger productivity (larger H) and a larger bill of mobility costs. We observe, however, that the former force dominates. Hence, the experience premium is increasing with the learning-by-doing and the technological level. The result that experience premium is increasing with the learning-by-doing is consistent with the human capital theory, which relates wages to productivity. With regard to our parameter on the technological level, Connolly and Gottschalk (2006) show that wage growth is more important for more-educated workers. This is consistent with our result that experience premium is increasing with B if we interpret B as the education level of young workers.

In contrast to the previous results, we obtain a non-monotonous relationship when we analyze the variety of knowledge, the learning-by-hiring and the elasticity of substitution among different types of experienced workers. An increase in learning-by-hiring (p) affects positively the amount of labor

⁹ Recall that with positive mobility costs the optimal amount of labor mobility is below the one that maximizes human capital (H). Thus, increasing the equilibrium level of labor mobility always increases H .

mobility. This implies an increase in the effective measure of human capital and a larger mobility costs bill. For low levels of learning-by-hiring the latter force dominates and experience premium is decreasing in p . However, as learning-by-hiring becomes more important, the productivity gain of the increased labor mobility compensates for the increase in mobility costs and then experience premium is increasing in p .

Similarly, the intuition for a U-shape relationship between variety of knowledge and experience premium can be understood by analyzing this trade-off between productivity and mobility costs. Recall that we find that variety of knowledge increases labor mobility. We obtain that for low values of F , increasing this parameter raises mobility costs more than productivity. However, as F is large enough, any increase in mobility costs is more than compensated by the increase in productivity. This explains the U-shape relationship between experience premium and variety of knowledge.

A similar intuition is behind the effect of the elasticity of substitution among different types of experienced workers. As different types of workers become more substitutable, there is a reduction in labor mobility in equilibrium and consequently there is a loss in productivity and a decrease in total mobility costs. When complementarities are very strong, the former effect is larger, thus experience premium decreases. However, when the degree of substitutability of workers becomes sufficiently large, the loss in productivity is more than compensated by the decrease in mobility costs. As a result, the elasticity of substitution has a U-shape relationship with the experience premium.

5. Conclusion

Why do some industries give larger returns to industry experience than others? We propose a model where labor mobility across firms affects wage growth in

an industry. The determinants of labor mobility within an industry explain then the differences in experience premium across industries. We find that experience premium is decreasing in mobility costs, while increasing in the learning-by-doing and the technological level of the industry. Interestingly, wage growth presents a U-shape relationship with the learning-by-hiring, the substitutability between different types of workers and the variety of knowledge in the industry. Additionally to the results on industry experience premium, in the symmetric equilibrium we obtain an extended TFP specification. Our extended TFP adds two variables to the traditional technological level of the firm. On the one hand, the learning-by-doing capability that a firm offers to their workers affects the TFP. On the other hand, the firm composition of experienced labor also determines firms' TFP. This result suggests that labor mobility may partially explain the differences in TFP across countries.

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Appendix

A. Proof of the existence and uniqueness of the symmetric equilibrium

We first rewrite equations (10)-(15) by introducing two new

variables: $x = \frac{\lambda}{\eta}$ and $k = \frac{K}{L}$.

$$\alpha A^\alpha B^{1-\alpha-\beta} \left(\frac{\eta}{L} \right)^{\alpha-1} k^\beta (1 + p(F-1)x^\sigma)^{\frac{\alpha}{\sigma}-1} = \omega, \quad (1.22)$$

$$p\alpha A^\alpha B^{1-\alpha-\beta} x^{\sigma-1} k^\beta \left(\frac{\eta}{L} \right)^{\alpha-1} (1 + p(F-1)x^\sigma)^{\frac{\alpha}{\sigma}-1} = \omega + m, \quad (1.23)$$

$$(1 - \alpha - \beta)A^\alpha B^{1-\alpha-\beta} k^\beta \left(\frac{\eta}{L}\right)^\alpha (1 + p(F-1)x^\sigma)^\frac{\alpha}{\sigma} = w, \quad (1.24)$$

$$\beta A^\alpha B^{1-\alpha-\beta} k^{\beta-1} \left(\frac{\eta}{L}\right)^\alpha (1 + p(F-1)x^\sigma)^\frac{\alpha}{\sigma} = r + 1, \quad (1.25)$$

$$L = \frac{N}{F}, \quad (1.26)$$

$$(F-1)x + 1 = \frac{L}{\eta}. \quad (1.27)$$

Using equation (25) and (27) we obtain k as a function of x .

$$k = \left(\frac{\beta A^\alpha B^{1-\alpha-\beta} (1 + p(F-1)x^\sigma)^\frac{\alpha}{\sigma}}{(1+r)((F-1)x+1)^\alpha} \right)^\frac{1}{1-\beta}. \quad (1.28)$$

Using equations (22) and (23) we equalize ω , and substitute k and η/L using the last equation and equation (27). Then we obtain one equation depending only on x , which can be written as:

$$px^{\sigma-1} = 1 + \frac{m(1+r)^\frac{\beta}{1-\beta} (1 + p(F-1)x^\sigma)^\frac{\sigma(1-\beta)-\alpha}{\sigma(1-\beta)}}{\alpha \beta^{1-\beta} A^{1-\beta} B^{1-\beta} (1 + (F-1)x)^\frac{1-\alpha-\beta}{1-\beta}}. \quad (1.29)$$

Next, we show that such equation has a solution, so the symmetric equilibrium exists. Let us denote any solution of equation (29) by x^* . Recall that we know from solving the model with zero mobility costs that if the equilibrium exists, x^* must be smaller than $p^\frac{1}{1-\sigma}$, and given that $p \in [0,1]$ and $\sigma < 1$, we know that $x^* \in [0,1]$. Thus, we focus on this region to find the equilibrium.

Since the functions are continuous, to prove that the equilibrium exists it is enough to show that in equation (29) $LHS(x=0) > RHS(x=0)$ and $LHS(x=1) < RHS(x=1)$. This means that they must cross at least once, so the equilibrium exists. At $x=0$ the LHS has a

vertical asymptote and the RHS is finite. At $x=1$ the $LHS = p < 1$ and it is trivial to check that the RHS is larger than 1. Therefore, the equilibrium exists.

Next, we prove uniqueness of equilibrium. The LHS of equation (29) is always positive, decreasing in x and convex.

$$\frac{\partial LHS}{\partial x} = p(\sigma - 1)x^{\sigma-2} < 0.$$

$$\frac{\partial^2 LHS}{\partial x^2} = p(1 - \sigma)(2 - \sigma)x^{\sigma-3} > 0.$$

Moreover, it is straight forward to check that the limit of the LHS when x goes to zero is infinity and the limit of the LHS when x goes to infinity is zero.

The RHS of equation (29) is always positive and the first derivative is the following:

$$\frac{\partial RHS}{\partial x} = - \frac{(1+r)^{\frac{\beta}{1-\beta}} (F-1)m(1+(F-1)px^\sigma)^{\frac{\alpha}{\sigma(1-\beta)}} \Psi(x)}{\beta^{\frac{\beta}{1-\beta}} A^{\frac{\alpha}{1-\beta}} B^{\frac{1-\alpha-\beta}{1-\beta}} \alpha(1-\beta)x(1+(F-1)x)^{\frac{1-\alpha-\beta}{1-\beta}+1}},$$

where

$$\Psi(x) = px^\sigma (\alpha - (1-\beta)\sigma + (1-\beta)(F-1)(1-\sigma)x) + x(1-\alpha-\beta).$$

The slope of the RHS depends on the sign of $\Psi(x)$. Notice that $\Psi(x)$ is always positive when $\alpha \geq (1-\beta)\sigma$. On the other hand, when $\alpha < (1-\beta)\sigma$, it is easy to check that $\Psi(x)$ is negative for all $x < \bar{x}$ and positive for $x > \bar{x}$, where \bar{x} is the solution to $\Psi(\bar{x}) = 0$.

Assumption

1. $\Psi(x^*) = px^{*\sigma} (\alpha - (1-\beta)\sigma + (1-\beta)(F-1)(1-\sigma)x^*) + x^*(1-\alpha-\beta) > 0$ for all x^* that solve equation (29).

Under assumption 1 the RHS is decreasing in equilibrium. Moreover, the LHS is steeper than the RHS in the first equilibrium. For both functions to cross a second time it must happen that the RHS is now steeper than the LHS. Hence, if the equilibrium is to be unique it cannot happen that the $\left| \frac{\partial RHS}{\partial x} \right| > \left| \frac{\partial LHS}{\partial x} \right|$ at any x^* that solves equation (29). Assumption 2 guarantees that $\left| \frac{\partial RHS}{\partial x} \right| < \left| \frac{\partial LHS}{\partial x} \right|$ at all x^* . Thus, when assumption 2 holds, the symmetric equilibrium is unique.

Assumption 2.

$$\Psi(x^*) < \frac{\beta^{\frac{\beta}{1-\beta}} A^{\frac{\alpha}{1-\beta}} B^{\frac{1-\alpha-\beta}{1-\beta}} \alpha(1-\beta)(1-\sigma)(1+(F-1)x^*)^{\frac{1-\alpha-\beta}{1-\beta}+1} px^{*\sigma-1}}{(F-1)m(1+r)^{\frac{\beta}{1-\beta}} (1+(F-1)px^{*\sigma})^{\frac{\alpha}{\sigma(1-\beta)}}} \text{ for all } x^* \text{ that}$$

solve equation (29).

To sum up, we proved that the equilibrium always exists. When $\alpha > (1-\beta)\sigma$, we need assumption 2 to prove that the equilibrium is unique. When $\alpha < (1-\beta)\sigma$, we need assumptions 1 and 2 to prove uniqueness of equilibrium. These assumptions were satisfied for all the simulation exercises performed.

B. Comparative analysis with mobility costs. Analytical proofs for the case $\alpha > (1-\beta)\sigma$.

In this section we provide the analytical proofs of the results of the comparative analysis in the case of $\alpha > (1-\beta)\sigma$ and positive mobility costs. We study how parameter changes affects labor mobility and experience premium in equilibrium. Some of the results require some assumptions to hold. All assumptions stated here hold in the simulation exercises of the paper.

B1. Results on labor mobility

We rewrite equation (29) to have $G = LHS - RHS = 0$ and differentiate with respect to the parameter. The sign of this derivative indicates how the parameter affects x^* .

Let Δ be the following expression:

$$\Delta = \left(A^{\frac{-\alpha}{1-\beta}} B^{\frac{-1+\alpha+\beta}{1-\beta}} (1 + (F-1)x)^{\frac{-1+\alpha+\beta}{1-\beta}} (1 + (F-1)px^\sigma)^{\frac{-\alpha}{\sigma(1-\beta)}} \right) \left(\frac{1+r}{\beta} \right)^{\frac{\beta}{1-\beta}}.$$

Notice that given the restrictions assumed on the parameters of the model Δ is always positive.

Variation of p

$$\frac{\partial G}{\partial p} = x^{\sigma-1} + \frac{x^\sigma (F-1)m(\alpha - (1-\beta)\sigma)}{\alpha(1-\beta)\sigma} \Delta.$$

Since we consider the case of $\alpha > (1-\beta)\sigma$, it is trivial to check that this derivative is positive. This implies that learning-by-hiring affects positively the labor mobility in equilibrium.

Variation of m

$$\frac{\partial G}{\partial m} = -\frac{1}{\alpha} (1 + (F-1)px^\sigma) \Delta < 0.$$

This derivative is negative, so an increase in mobility costs always results in a decrease in labor mobility.

Variation of A

$$\frac{\partial G}{\partial A} = \frac{m(1 + (F-1)px^\sigma)}{(1-\beta)A} \Delta > 0.$$

This derivative is positive, so an increase in the learning-by-doing always results in larger labor mobility in equilibrium.

Variation of B

$$\frac{\partial G}{\partial B} = \frac{(1-\alpha-\beta)m(1 + (F-1)px^\sigma)}{\alpha(1-\beta)B} \Delta > 0.$$

This derivative is positive, so an increase in the technological level always results in larger labor mobility in equilibrium.

Variation of F

$$\frac{\partial G}{\partial F} = -\frac{m(px^\sigma(\sigma(1-\beta) - \alpha(1+(F-1)(1-\sigma)x) - (1-\alpha-\beta)\sigma x))}{\alpha(1-\beta)\sigma(1+(F-1)x)} \Delta.$$

Since $\alpha > (1-\beta)\sigma$, it is trivial to check that this derivative is positive. Notice additionally that the effect on total mobility ($F\lambda$) is also positive.

Variation of σ

$$\begin{aligned} \frac{\partial G}{\partial \sigma} = & px^{\sigma-1} \text{Log}[x] + \frac{m(1+(F-1)px^\sigma)}{\alpha(1-\beta)\sigma^2} \Delta^* \\ & * \left((F-1)p\sigma(\alpha - (1-\beta)\sigma)x^\sigma \text{Log}[x] - \alpha(1+(F-1)px^\sigma) \text{Log}[1+(F-1)px^\sigma] \right). \end{aligned}$$

Notice that since in equilibrium $0 < x^* < 1$, then $\text{Log}[x^*] < 0$ and $\text{Log}[1+(F-1)px^{*\sigma}] > 0$. Then, it is easy to check that since $\alpha > (1-\beta)\sigma$ the derivative has a negative sign. This means that the more substitutable are the different types of experienced workers, the less labor mobility there will be in equilibrium.

B2. Results on experience premium

From equations (15) and (17) we obtain:

$$\frac{\omega}{w} = \frac{\alpha(1+(F-1)x)}{(1-\alpha-\beta)(1+p(F-1)x^\sigma)}. \quad (1.30)$$

We use this expression together with the results on labor mobility to check how the experience premium depends on each parameter.

Let us define $\Gamma = 1 - px^{\sigma-1}(\sigma - (F-1)(1-\sigma)x)$. Hereinafter we assume that Γ is positive in equilibrium. This assumption is satisfied in all the simulation exercises of the paper.

Assumption 3.

$\Gamma = 1 - px^{*\sigma-1}(\sigma - (F-1)(1-\sigma)x^*) > 0$ for all x^* that solve equation (29).

Variation of p

$$\frac{\partial \frac{\omega}{w}}{\partial p} = \frac{\alpha(F-1)\left(\frac{\partial x}{\partial p}\Gamma - (1+(F-1)x)x^\sigma\right)}{(1-\alpha-\beta)(1+p(F-1)x^\sigma)^2}.$$

We showed in appendix B.1 that $\frac{\partial x}{\partial p}$ is positive. Then the effect of learning-by-

hiring on experience premium is ambiguous. When $\frac{\partial x}{\partial p}\Gamma > (1+(F-1)x)x^\sigma$, then

the learning-by-hiring affects positively the equilibrium experience premium.

Otherwise, the effect is negative.

Variation of m

$$\frac{\partial \frac{\omega}{w}}{\partial m} = \frac{\alpha(F-1)\Gamma}{(1-\alpha-\beta)(1+(F-1)px^\sigma)^2} \frac{\partial x}{\partial m} < 0.$$

This derivative is negative. Therefore, experience premium is decreasing in mobility costs.

Variation of A

$$\frac{\partial \frac{\omega}{w}}{\partial A} = \frac{\alpha(F-1)\Gamma}{(1-\alpha-\beta)(1+(F-1)px^\sigma)^2} \frac{\partial x}{\partial A} > 0.$$

We obtain a positive impact of learning-by-doing on experience premium.

Variation of B

$$\frac{\partial \frac{\omega}{w}}{\partial B} = \frac{\alpha(F-1)\Gamma}{(1-\alpha-\beta)(1+(F-1)px^\sigma)^2} \frac{\partial x}{\partial B} > 0.$$

We obtain a positive impact of technological level on experience premium.

Variation of F

$$\frac{\partial \frac{\omega}{w}}{\partial F} = \frac{\alpha[(F-1)\frac{\partial x}{\partial F}\Gamma - x(px^{\sigma-1} - 1)]}{(1-\alpha-\beta)(1+p(F-1)x^\sigma)^2}.$$

We showed in appendix B.1 that $\frac{\partial x}{\partial F} > 0$. Then the effect of F on experience premium is ambiguous. Notice that the first term in the numerator is positive. Recall that in equilibrium $x < p^{\frac{1}{1-\sigma}}$. Then the last term in the numerator is negative. For low levels of F the negative effect dominates and variety of knowledge affects negatively the equilibrium experience premium, while for high levels of F the total effect of variety of knowledge on experience premium is positive.

Variation of σ

$$\frac{\partial \frac{\omega}{w}}{\partial \sigma} = \frac{\alpha(F-1)\left(\frac{\partial x}{\partial \sigma}\Gamma - px^\sigma(1+(F-1)x)\text{Log}[x]\right)}{(1-\alpha-\beta)(1+p(F-1)x^\sigma)^2}.$$

We showed in appendix B.1 that $\frac{\partial x}{\partial \sigma} < 0$. Then the sign of this derivative is

ambiguous. If $\left|px^\sigma(1+(F-1)x)\text{Log}[x]\right| > \left|\frac{\partial x}{\partial \sigma}\Gamma\right|$, the elasticity of substitution

affects positively the equilibrium experience premium. Otherwise the effect is negative.