Wage Elasticities of the Supply of R&D Workers in the Netherlands

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Abstract

Endogenous growth theory shows the crucial importance of R&D for economic growth. However, the effectiveness of R&D policies is limited by the low wage elasticities of the supply of R&D workers. Estimating these elasticities for the Netherlands is hampered by the lack of appropriate micro-data. The empirical literature suggests that estimating wage elasticities from macro-data may be impossible. However, we show that the identification problem can be solved by performing the instrumental variables approach in a cointegration framework. We apply this estimation approach to macro-data from the R&D Survey of Statistics Netherlands. The wage elasticity of the supply of R&D workers in the Netherlands is 0.96 in the short run and 1.20 in the long run. When R&D expenditure is increased, the demand side of the labour market for R&D workers compensates for the short-run inflexibility of the supply side by strong wage increases in the short run and weaker responses in the long run. As a result, a 1.0% increase in real R&D spending will lead to a 0.5% increase in the employment of R&D workers, both in the short run and in the long run.

Theme: Labour Supply
Keywords: Wage Elasticities, R&D, Cointegration
JEL-Code: J22, J44, O38

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1. Introduction

An important insight from endogenous growth theory is that R&D is of crucial importance for economic growth (Romer, 1990). However, knowledge spillovers could lead to a sub-optimal level of knowledge activities in the private sector. The public sector may play a supporting role by means of subsidies, R&D by quasi-public organizations and government investments in knowledge infrastructure. The problem with this type of public intervention is that there might be an insufficient supply of people who possess the skills to perform the additional research projects adequately. Since R&D activities require highly skilled specialists, it will take a long period of time for the educational system to adapt to a higher demand for such graduates. If the market mechanism performs well on this segment of the labour market, this rise in demand will not lead to open vacancies, but will push up wages due to a competition between many employers for a limited number of R&D workers.

Also in the long run – when the educational system has enough time to respond – the demand for R&D workers might be limited. If only a fraction of the pupils at school has enough talent for and interest in a career in research, the 'production of human capital' in this field will be limited. An increased lure for these research jobs might attract less talented pupils, lowering the productivity of this creative work.

Public investments in R&D to stimulate research might therefore lead to crowding out of the private sector by the public sector via rising wages and to higher costs for both the public and the private sector. In this case the policy measures primarily lead to a wage rise for R&D workers instead of an increase in knowledge activities. Goolsbee (1998) shows for the US that the income of R&D workers in occupations in which federal R&D expenditure plays an important role and indeed depends significantly on federal R&D expenditure. He estimates that a 1% increase in total R&D expenditure will increase wages by 0.3%. Federal R&D expenditures on their own – varying between 61 and 34% of the total R&D budget – might increase wages of all R&D workers with 0.23% for each percent increase in budget. For Europe in general and especially for the Netherlands no such estimates are available.

From a policy perspective it is therefore important to get insight in the reaction of the supply of R&D workers and their wages to an increase in the demand for R&D. These elasticities of supply determine the limits to public intervention in the R&D market. As remarked before, it is important to distinguish between short-run and long-run adjustments of supply and between workers with a relevant educational background and those who actually work in R&D. A large accumulation of human capital is embodied in R&D workers, which takes many years of education and training. As a consequence, the supply of R&D workers might be very inelastic in the short run. The educational choice of new cohorts can only lead to considerable adjustments of the supply of R&D workers in the long run. According to the human capital theory of Mincer (1958), Schultz (1961) and Becker (1962), the willingness of individuals to invest in their own human capital depends on the expected additional flow of future income which results from this investment. The model of Heckman et al. (1998) gives a good description of these short-run and long-run dynamics. However, In the short run supply can only be increased by the inflow of workers who are already qualified, but do not work in R&D at the moment or by increased supply in units of working time of the existing stock of knowledge workers. The choice of education is only the first step towards a career as a knowledge worker. The next steps take place after graduation and during the career. In the Netherlands about half of all technically educated end up in a non-technical occupation: in 1995 this was the case for 46% of graduates from higher vocational technical education and for 54% of technical university graduates (Borghans et al., 1995). For R&D occupations this percentage is even higher. This is caused on the one hand because of the technologization of non-technical occupations – i.e. in more and more non-technical occupations, technical skills become valuable due to the introduction of computers and other technology – and the fact that technical professionals continue their career in managerial jobs, and on the other hand because technical occupations are often sensitive to the business cycle and thus non-technical occupations offer good employment opportunities during bad times (Borghans et al., 1997). However, there is some evidence that technically educated workers in non-technical occupations do not easily return to R&D occupations at the moment demand increases in the R&D sector. This may be caused by selection based on R&D talent and skills obsolescence, which especially occurs in these technical jobs. Additional demand for R&D could therefore lead to a loss of quality. It is therefore important to distinguish between technically educated and the subset that we could properly call R&D workers. If it is difficult to substitute R&D workers by other technically educated, the effect of additional R&D activities on wages could be very strong.

The objective of this study is therefore to assess the effects of additional R&D expenditure on wages of R&D workers and the supply of R&D workers in the Netherlands, both in the short run and in the long run. This will give us an indication of the costs of and the limits to expanded research activities.

The determination of the wage elasticity of supply of R&D workers in the Netherlands is however hampered by both the availability of data and by econometric problems. For the Netherlands there are no such detailed micro-data as are available for the US (as used by Goolsbee, 1998). The most important source of information on R&D workers in the Netherlands is the R&D Survey of Statistics Netherlands, which is a macro-dataset. However, we will propose a combination of the instrumental variables approach and cointegration techniques to deal with the identification problem of estimating wage elasticities from macro-data.

The remainder of this paper is organized as follows. In section 2 the three key variables of the study are discussed: R&D expenditure, wages and employment. Section 3 adresses the econometric pitfalls in estimating wage elasticities and proposes an estimation approach based on the instrumental variables method and cointegration analysis which deals with the identification problem and the non-stationarity of macro-data. The estimation results are presented in section 4. Section 5 concludes.

2. R&D expenditure, wages and activities

The three key variables of this study are R&D expenditure, wages and activities, where activities can be measured in terms of employment. At first sight, the most interesting causality is the direct effect of R&D expenditure on R&D activities. If we denote R&D expenditure by x and R&D employment by n (both in natural logarithms), the relationship may be estimated from the following regression equation.

$$n \ ' \ 2 \ \% \ \$ \ x \ \% \ \mu \qquad (2.1)$$

Since the variables are expressed in natural logarithms, the estimated parameter $\$$ can be interpreted as the *R&D expenditure elasticity of R&D employment*: a 1% increase in R&D expenditure will lead to a $\$\%$ increase in R&D employment. From a policy perspective, this elasticity indicates the effectiveness of increased government R&D spending on economy-wide knowledge activities. However, this elasticity gives no insight in the underlying problems on the labour market for R&D workers. For example, if a large portion of the additional R&D expenditure is used for non-labour expenses - such as computers, machines, buildings etc. - then it is obvious that the effect on R&D employment will be limited. In this case a low R&D expenditure elasticity of R&D employment is explained by factors on the demand side of the labour market for R&D workers. At the same time, there may also be supply side factors at work. The large stock of human capital which is embodied in R&D workers takes considerable time to accumulate, hence the supply of R&D workers may not be very elastic. As a result, the effectiveness of the portion of R&D expenditure which is used for labour expenses is limited by the wage elasticity of the supply of R&D workers. For policy-makers it can be very informative to know on which side of the labour market the limited effectiveness of R&D expenditure originates. If wage elasticities of supply are low, then increasing R&D expenditure may not be sufficient to attain policy objectives. Measures will have to be taken to increase the number of graduates which opt for a career in R&D. Since the education and training of R&D workers takes a lot of time, such a supply-side policy will take some time to get results.

In order to disentangle the demand side effects from the supply side effects, the following two regression equations can be estimated. On the demand side, the effect of R&D expenditure on wages can be captured by wage equation (2.2), where w denotes the natural logarithm of wages.

$$w \;\text{'}\; 2_w \;\%\; \$_w \, x \;\%\; \mu_w \tag{2.2}$$

Due to the formulation in natural logarithms, the estimated parameter $\$_w$ can be interpreted as the *R&D expenditure elasticity of wages*. A 1% increase in R&D expenditure will lead to a $\$_w$% increase in wages.

On the supply side, the effect of wages on labour supply can be estimated by labour supply equation (2.3).

$$n \;\text{'}\; 2_n \;\%\; \$_n \, w \;\%\; \mu_n \tag{2.3}$$

The estimated parameter $\$_n$ is the *wage elasticity of the supply of R&D workers*: if wages are increased by 1%, then the supply of R&D workers increases by $\$_n$%.

By looking at all three elasticities obtained from equations (2.1)-(2.3), we are able to get a clear picture of the labour market for R&D workers. A 1% increase in R&D expenditure will lead in a $\$_w$% increase in wages. Given the fact that a 1% increase in wages leads to a $\$_n$% increase in the supply of R&D workers, the net effect of the 1% increase in R&D expenditure is a $% increase in R&D activities, as measured by R&D employment. In other words, the three elasticities allow us to separate the demand side factors from the supply side factors which explain the effectiveness of R&D expenditure in stimulating R&D activities.

3. Estimating wage elasticities from macro-data

The empirical analysis of the interactions between R&D expenditure, wages and activities focusses on three types of elasticities estimated from three equations. The supply side effects are captured by the wage elasticity of labour supply, estimated from labour supply equation (2.3). The demand side effects are reflected by the R&D expenditure elasticity of wages, which is estimated from wage equation (2.2). The net effect of R&D expenditure is measured by the R&D expenditure elasticity of R&D employment, estimated from equation (2.1). In this section we discuss two econometric pitfalls which hamper the estimation of these elasticities. The first issue is the identification problem which arises when we use data on wages and employment, since they are in fact the net results of the interaction between supply and demand. The second problem is the possible non-stationarity of macroeconomic variables.

The identification problem is a long-standing issue in econometrics, which is caused by the fact that we do not directly observe demand and supply functions. The observed data on wages and employment may be in fact equilibrium outcomes of adjustment processes between labour supply and labour demand. In other words, we only observe the intersections of labour supply curves and labour demand curves, which makes it difficult to spot the location of the labour supply curve. As a result of the identification problem, the wages which appear in labour supply equations such as (2.3) are clearly endogenous regressors. Hence one of the assumptions on which the usual test-statistics of the Ordinary Least Squares (OLS) method are based, i.e. the exogeneity of regressors, is violated. Demand effects on the wage rate cloud the relationship between wages and labour supply in the regression equation. The conventional remedy for problems of endogenous regressors is the Instrumental Variable (IV) method. The idea is to filter out the demand effects in the wage rate by performing an auxiliary regression which explains wages in terms of demand factors, see for example Kennan (1988) and Kimmel & Kniesner (1998). Wage equation (2.2) suits this purpose very well: R&D expenditure captures the demand influences on wages and may thus serve as an instrument. After estimating this auxiliary equation, the instrumental variable ("instrumented wages") is computed as the systematic part of regression equation (2.2).

$$\tilde{w} = \hat{\alpha}_w + \hat{\beta}_w x \tag{3.1}$$

The IV-estimator of the wage elasticity is then found by estimating a labour supply equation in which wages are replaced by instrumented wages.

$$n = \alpha_n + \beta_n \tilde{w} + \varepsilon_n \tag{3.2}$$

For micro data, this approach indeed yields positive wage elasticities of supply. For example, Goolsbee (1998) obtains highly significant estimates between 0.1 and 0.2. The identification problem is relatively minor if we estimate supply curves on the basis of micro data. Shifts in the wage-supply plane of labour supply curves are caused by other supply-determining factors, such as demographics. The demographic characteristics of the labour supply as a whole may have a variability that is too large compared with the variability of the labour demand curve, to allow identification of an aggregate labour supply curve. Micro data allow us to take the individual heterogeneity into account which determines the location of the individual labour supply curve. These individual supply curves will be subject to relatively minor shifts, as the demographic characteristics of an individual are less variable. At the same time, the position of the labour demand curve will still be relatively variable, allowing identification of the individual labour supply curve.

Unfortunately, the literature on estimating wage elasticities from *macro data* shows that empirical estimations of aggregate labour supply functions usually yield negative or insignificant wage elasticities of supply (Kniesner & Goldsmith, 1987). As a matter of fact, Kimmel and Kniesner (1998) state that *"Identifying labor supply with macro data may be impossible. There is much macro empirical research acknowledging the identification problem in labor supply and attempting to find the reasons underlying the difficulty in separating the labor supply responses to macro demand disturbances".* This might be a serious problem for this study, as the most informative data available on R&D workers in the Netherlands is the R&D Survey of Statistics Netherlands, which is a macro dataset. However, we will show that the remedy for the second econometric pitfall, the possible non-stationarity of macroeconomic regressors, also solves the first econometric pitfall: the identification problem.
The non-stationarity of macroeconomic regressors is an issue which has emerged in the 1980s, see for example Nelson & Plosser (1982). From unit root tests which we performed on time series from the R&D Survey of Statistics Netherlands it appears that the variables involved, R&D expenditure, wages and labour supply are indeed non-stationary. The non-stationarity of regressors is another violation of the

assumptions on which the usual test-statistics of the OLS method are based. As a result, straightforward regressions between non-stationary variables lead to misleading inferences. The proper way to study causalities between non-stationary variables is to find co-integrating relationships and to estimate error correction mechanisms. As a matter of fact, according to the Engle & Granger Representation Theorem, a co-integrating relationship implies the existence of an ECM (Engle & Granger, 1987).

Since the identification problem requires an IV-approach, we will use a combination of the IV-method and the ECM-approach to avoid the first two econometric pitfalls. Our approach follows the traditional route of first estimating a wage equation to form instrumental variables for the estimation of the labour supply equation. The non-stationarity of the key variables implies that the appropriate way to apply the instrumental variable approach is to try to find cointegrating relationships between the non-stationary variables. In other words, both the wage equation and the labour supply equation are estimated in the form of error correction mechanisms. Each error correction mechanism is estimated by the two step approach by Engle and Granger (1987). As a result, the estimation procedure that we use in this paper to obtain wage elasticities of the supply of knowledge workers can be summarized by equations (3.3)-(3.6).

The wage equations are given by (3.3) and (3.4).

$$w_t = \alpha_w + \beta_w x_t + \mu_{w,t} \qquad (3.3)$$

Equation (3.3) yields super-consistent estimates of β_w and α_w, which are inserted in equation (3.4).

$$\Delta w_t = \gamma_w \Delta x_t + \lambda_w \left(w_{t-1} - \hat{\alpha}_w - \hat{\beta}_w x_{t-1}\right) + \varepsilon_{w,t} \qquad (3.4)$$

Since wages and R&D expenditure are expressed in natural logarithms, we can interpret both γ_w and β_w as *R&D expenditure elasticities of wages*. Since γ_w measures the immediate effect of the change in R&D expenditure on the change in wages, it can be interpreted as a short-term elasticity. The coefficient β_w represents the long-term equilibrium relationship between wages and R&D expenditure and can therefore be interpreted as a long-term elasticity. The parameter λ_w indicates the speed of adjustment to the long-term equilibrium. After (3.4) is estimated, we use the results to form an instrumental variable version of wages, which is used for the estimation of the labour supply equations (3.5) and (3.6), yielding the *wage elasticities of the supply of R&D workers*.

$$n_t = \alpha_n + \beta_n \tilde{w}_t + \mu_{n,t} \qquad (3.5)$$

$$\Delta n_t = \gamma_n \Delta \tilde{w}_t + \lambda_n \left(n_{t-1} - \hat{\alpha}_n - \hat{\beta}_n \tilde{w}_{t-1}\right) + \varepsilon_{n,t} \qquad (3.6)$$

In section 4, the estimation results show that this procedure not only deals with the non-stationarity problem, but also with the identification problem. The estimation of the R&D expenditure elasticity of R&D employment does not suffer from an identification problem, but the non-stationarity still calls for the estimation of an ECM. The short-term and long-term R&D expenditure elasticities of the employment of R&D workers are estimated on the basis of equations (3.7) and (3.8).

$$n_t = \theta + \beta x_t + \mu_t \tag{3.7}$$

$$\Delta n_t = \alpha \Delta x_t + \gamma \left(n_{t-1} - \hat{\theta} - \hat{\beta} x_{t-1}\right) + \varepsilon_t \tag{3.8}$$

Hamermesh (1999) suggests that recent developments in dynamic econometrics, which have been applied successfully in macroeconomics and finance, deserve more attention from labour economists. In this paper, we show that applying cointegration techniques can be a fruitful approach to deal with the identification problem of estimating wage elasticities of supply from macro data.

4. Estimation results

A macro data set which is specifically aimed at R&D workers in the Netherlands is the R&D Survey (*R&D Enquête*) of Statistics Netherlands *(Centraal Bureau voor de Statistiek*). This annual survey is aimed at collecting data on R&D expenditure and R&D employment in the various sectors of the Dutch economy. Data on gross wage expenditure are available, which makes the R&D Survey suited for our purposes. Three variables for each of 19 sectors of the Dutch economy and for the aggregate of these sectors, are constructed from the R&D Survey for the empirical analysis in this section. We compute real annual R&D expenditure, with base year 1990, deflating by PPI. R&D employment is measured in terms of R&D workers, expressed in annual full-time equivalents (FTEs). The real gross annual wage rate is computed as the quotient of the annual gross wage costs in real terms (base year = 1990, deflated by CPI) and R&D employment.

In order to avoid problems with changes in classifications, which might cause serious problems for sensitive models such as error correction mechanisms, we use data from 1973 to 1993.

Unit root tests (Dickey-Fuller) reject the stationarity of R&D expenditure, wages and R&D employment in all nineteen sectors of the Dutch economy and the aggregate level (all sectors combined). The corresponding first differences are all stationary, hence we are dealing with I(1)-variables.

The *R&D expenditure elasticities of wages* estimated from equations (3.3) and (3.4) are summarized in table 1. Each row contains the results for a specific sector, indicated by the first column. The final row displays the estimation results at the aggregate level (all sectors). The last column shows the long-term elasticity estimated from equation (3.3). Since the test statistics from that equation do not have standard distributions, due to the non-stationarity of the variables involved, standard errors are not added to the estimated coefficient. The remaining columns show the estimated coefficients from equation (3.4), with corresponding standard errors, the Breusch-Godfrey Lagrange Multiplier test for first order serial correlation and the R^2. The estimated coefficients from (3.4) are the short-term elasticity and the adjustment speed at which wages return to the long-term equilibrium relationship with R&D expenditure.

Table 1 shows that all estimated short-term elasticities are positive and significant at the 5% level, except for university-affiliated institutions. Cointegration of R&D expenditure and wages is rejected (Dickey-Fuller tests, not reported here) in only four sectors: transport, communication and commercial services, agriculture and fisheries, electricity, gas and water and research enterprises. At the aggregate level cointegration is accepted. Despite the encouraging results of the cointegration tests, the estimated adjustment speed coefficients are insignificant in about half of the sectors, among which the four sectors for which cointegration was rejected. On the other hand, all adjustment speed coefficients have the plausible negative sign. We do not drop the disequilibrium term from regression equation (3.4), since this may introduce omitted variable bias in the estimation of the short-term elasticity. Possible non-stationarity of the disequilibrium term may not be much of a problem, as the weak power of Dickey-Fuller tests often leads to an an incorrect rejection of cointegration. At the aggregate level the adjustment speed coefficient is significant, hence we conclude that there is a long-term equilibrium relationship between wages and R&D expenditure, although the speed at which wages return to the equilibrium level is difficult to estimate precisely in various sectors. With exception of a few sectors, the error correction mechanism adequately captures the short-term and long-term dynamics as indicated by the low LM-values. The R^2 ranges between 0.44 and 0.98, which is satisfactory.

At the aggregate level, the short-term elasticity is 0.52 and the long-term elasticity is 0.38. At the sector level, the short-term elasticities vary between 0.34 and 1.25, while the long-term elasticities range from 0.35 to 1.06. In about two thirds of the sectors, the long-term elasticity is smaller than the short-term elasticity. We conclude that in most sectors a permanent increase in R&D expenditure has an upward effect on wages which is somewhat smaller in the long run. Short-term elasticities larger than 1.00 are found in three sectors: food and beverage, universities and TNO. In these sectors R&D expenditure has relatively strong upward effects on wages within one year. Short-term elasticities smaller than 0.50 hold for metal industries, the rubber and synthetic industry. The short-term elasticity for university-affiliated institutions is insignificantly different from zero. In these sectors R&D expenditure has little upward effect on wages in the short run. A long-term elasticity larger than 1.00 is found only for construction and installation, with a significant adjustment speed coefficient. Long-term elasticities smaller than 0.50 hold for three sectors: metal industries, transport, communication and commercial services, and universities. Negative long-term elasticities with significant adjustment speed coefficients were initially estimated for government institutions and university-affiliated institutions. In table 1 however, we report the estimate after the constant term from equation (3.3) is dropped. The short-term elasticities that were estimated with the negative long-term elasticities in the disequilibrium term were -1.05 (insignificant) for government institutions and -0.82 (barely significant) for university-affiliated institutions. In other words, there is some evidence that R&D expenditure has a perverse effect on wages in government institutions and university-affiliated institutions.

Notice that the short-term and long-term R&D expenditure elasticities of wages in metal industries are both small, indicating that R&D expenditure has a modest overall effect on wages. On the other hand, for universities we find a large short-term elasticity and a small long-term elasticity, which means that R&D expenditure has a strong effect on university wages within one year, but a weak effect on the long run.

Table 1: R&D expenditure elasticities of wages

sector	short-term elasticity "	adjustment speed (	LM	R^2	long-term elasticity $
Metal industries	0.40* (0.10)	-0.38 (0.23)	0.66	0.65	0.35
Chemicals and pharmaceuticals	0.79* (0.16)	-0.21 (0.23)	5.51*	0.72	0.52
Food and beverage industry	1.06* (0.10)	-0.15 (0.17)	0.22	0.89	0.60
Rubber and synthetic industry	0.34* (0.08)	-0.63* (0.21)	0.82	0.52	0.54
Timber, furniture, paper and graphic industries	0.82* (0.08)	-0.20 (0.13)	0.24	0.89	0.73
Textile, clothing and leather industries	0.76* (0.13)	-0.60 (0.36)	1.11	0.73	0.69
Building materials	0.56* (0.09)	-0.67* (0.23)	0.09	0.69	0.64
Transport, communication and commercial services	0.90* (0.21)	-0.26 (0.21)	0.31	0.58	0.47
Agriculture and fisheries	0.82* (0.15)	-0.20 (0.15)	0.13	0.65	0.88
Construction and installation	0.98* (0.12)	-0.88* (0.27)	1.35	0.80	1.06
Electricity, gas and water	0.99* (0.10)	-0.22 (0.13)	0.06	0.84	0.84
Research enterprises	0.76* (0.15)	-0.18 (0.16)	2.68	0.60	0.97
Other industry	0.85* (0.05)	-0.98* (0.23)	2.09	0.93	0.93
Universities	1.08* (0.29)	-1.08* (0.21)	0.76	0.73	0.47
Government institutions	0.53* (0.17) 0.05 (0.18)	-0.01 (0.06)	0.44	0.39	0.98
Semi-government institutions	0.85* (0.36)	-0.95* (0.13)	18.77*	0.78	0.74
TNO	1.25* (0.53)	-1.03* (0.09)	18.41*	0.89	0.81
PNP	0.60* (0.09)	-0.44* (0.16)	1.46	0.72	0.52
University-affiliated institutions	0.43 (0.28)	-0.80* (0.08)	17.10*	0.86	0.98
All sectors	0.52* (0.16)	-0.62* (0.24)	0.05	0.63	0.38

Estimation method: OLS, standard errors between brackets, asterisk denotes 5% significance
LM: Breusch-Godfrey Lagrange Multiplier test for first order serial correlation, asterisk denotes 5% significance

The short-term and long-term *wage elasticities of the supply of R&D workers* are given in table 2, which contains the estimation results of equations (3.5) and (3.6). All estimated short-term elasticities are positive and significant at the 5% level. Cointegration of R&D employment and instrumented wages is rejected (Dickey-Fuller tests) in 8 out of 19 sectors, but not at the aggregate level. The estimated adjustment speed coefficients are insignificant in all sectors for which cointegration was rejected and two additional sectors. However, all the adjustment speed coefficients have the plausible negative sign. We do not drop the disequilibrium term from regression equation (3.6), because of the risk of introducing omitted variable bias in the estimation of the short-term elasticity. Possible non-stationarity of the disequilibrium term may be a minor problem, as the weak power of Dickey-Fuller tests often leads to an an incorrect rejection of cointegration. At the aggregate level the adjustment speed coefficient is significant, hence we conclude that there is a long-term equilibrium relationship between supply and wages, although the speed at which wages return to the long-run equilibrium level is difficult to estimate precisely in about half of the sectors. With exception of a few sectors, the error correction mechanism

adequately captures the short-term and long-term dynamics as indicated by the low LM-values. The R^2 ranges from 0.48 to 0.99, which is satisfactory.
At the aggregate level, the short-term elasticity is 0.96 and the long-term elasticity is 1.20. At the sector level, the short-term elasticities vary between 0.37 and 1.19, while the long-term elasticities range from 0.45 to 1.74. In most business enterprise sectors, the long-term elasticity is smaller than the short-term elasticity. Hence wage changes have a relatively fast impact on supply. For universities, PNPs, university-affiliated institutions and research enterprises, the opposite is true, which means that wages affect the level of knowledge activities relatively slowly. Since research in universities has a stronger emphasis on basic research than on applied research, the elasticities indicate that an increase in basic research activities takes considerable time. This may reflect the large stock of accumulated knowledge that is embodied in basic researchers.

Large short-term and long-term elasticities are found for universities (1.19 and 1.74), university-affiliated institutions (1.13 and 1.08) and construction and installation (1.08 and 1.06). Hence wages have strong overall effects on supply in these sectors. The higher level of the elasticities for universities may reflect the lower wage level, which causes a higher sensitivity of supply to wages, than in most business enterprise sectors. As a result, even though university wages have a relatively stronger effect on supply in the long run, the effects are high both in the short and the long run compared with other sectors in the economy. A large short-term elasticity is also found for metal industries (1.11), while a large long-term elasticity holds for research enterprises (1.06). The results for university-affiliated institutions are robust with respect to the implementation of the instrumental variables approach. The instrumented wages were formed based on equation (3.5) without the constant term, but it is interesting to mention the estimated wage elasticities based on equation (3.5) with the constant term included. Remember that in this case the long-term R&D expenditure elasticity of wages was negative. The short-term and long-term wage elasticities of supply are 1.06 and 1.05 (both significant). The result for government institutions is less robust, in particular with respect to the short-term wage elasticity of supply. When wages are instrumented on the basis of equation (3.3) with the constant term included, the short-term wage elasticity of supply changes from 1.05 (significant) to insignificant (0.38), while the long-term elasticity slightly reduces to 1.00 (with an insignificant adjustment speed).

On the other side of the spectrum, the short-term and long-term elasticities for electricity, gas and water are both low (0.37 and 0.49). Hence wage increases will have a modest overall effect on supply. Other small short-term elasticities hold for PNPs (0.58) and textile, clothing and leather industries (0.63). Small long-term elasticities are found for chemicals and pharmaceuticals (0.45), food and beverage (0.48).

Table 2: Wage elasticities of the supply of R&D workers

sector	short-term elasticity "	adjustment speed (	LM	R^2	long-term elasticity $
Metal industries	1.11* (0.27)	-0.92* (0.21)	2.28	0.63	0.93
Chemicals and pharmaceuticals	0.65* (0.17)	-0.28* (0.21)	0.93	0.62	0.45
Food and beverage industry	0.86* (0.08)	-0.16 (0.11)	2.02	0.89	0.48
Rubber and synthetic industry	1.04* (0.23)	-0.71* (0.24)	3.26	0.55	0.94
Timber, furniture, paper and graphic industries	1.06* (0.12)	-0.56* (0.23)	2.54	0.84	1.02
Textile, clothing and leather industries	0.63* (0.20)	-0.55 (0.39)	0.19	0.48	0.51
Building materials	0.85* (0.21)	-0.72* (0.25)	0.65	0.58	0.69
Transport, communication and commercial services	0.96* (0.22)	-0.39 (0.22)	1.82	0.54	1.04
Agriculture and fisheries	0.89* (0.12)	-0.28 (0.20)	0.27	0.76	0.93
Construction and installation	1.08* (0.14)	-0.31 (0.23)	0.71	0.80	1.06
Electricity, gas and water	0.37* (0.12)	-1.10* (0.23)	0.79	0.64	0.49
Research enterprises	0.85* (0.14)	-0.11 (0.20)	0.12	0.69	1.06
Other industry	0.63* (0.09)	-0.28 (0.24)	2.38	0.75	0.96
Universities	1.19* (0.21)	-0.78* (0.21)	0.01	0.65	1.74
Government institutions	1.05* (0.03)	-0.25 (0.14)	2.50	0.99	1.08
Semi-government institutions	0.89* (0.04)	-0.08 (0.09)	5.20*	0.96	1.02
TNO	0.98* (0.02)	-0.26 (0.26)	0.61	0.99	0.95
PNP	0.58* (0.10)	-0.38* (0.16)	0.33	0.68	0.85
University-affiliated institutions	1.13* (0.05)	-0.96* (0.20)	16.69*	0.96	1.01
All sectors	0.96* (0.22)	-0.38* (0.16)	0.03	0.54	1.20

Estimation method: OLS, standard errors between brackets, asterisk denotes 5% significance
LM: Breusch-Godfrey Lagrange Multiplier test for first order serial correlation, asterisk denotes 5% significance

The instrumental variable approach followed in estimating equations (3.3)-(3.6) is aimed at disentangling demand and supply effects on the labour market for R&D workers. The R&D expenditure elasticity of wages tries to capture demand effects, such that the instrumented wages that can be formed based on equation (3.4) can be used to estimate labour supply equation (3.6). However, it is also interesting to directly estimate the effect of R&D expenditure on R&D employment. The resulting *R&D expenditure elasticity of R&D employment* reflects both demand and supply conditions. (Hence the terminology “employment” instead of “supply”.) Since R&D employment and R&D expenditure are non-stationary variables, the cointegration approach will also be followed, as described in equations (3.7) and (3.8).

The short-term and long-term R&D expenditure elasticities of the employment of R&D workers are given in table 3, which shows the estimation results of equations (3.7) and (3.8). All estimated short-term elasticities are positive and significant at the 5% level, except for government institutions. Cointegration is rejected (Dickey-Fuller tests) in five sectors, but not at the aggregate level. All adjustment speed coefficients are negative, however they are not significant in about half of the sectors, including the sectors for which cointegration was rejected. We include the disequilibrium term from regression equation (3.8) in order to avoid omitted variable bias in the estimation of the short-term elasticity. Possible non-stationarity of the disequilibrium term may be a limited problem, as the weak power of Dickey-Fuller tests often leads to an an incorrect rejection of cointegration. At the aggregate level the adjustment speed coefficient is significant, hence we conclude that there is a long-term equilibrium relationship between R&D employment and R&D expenditure, although the speed at which wages return to the equilibrium level are difficult to estimate precisely in about half of the sectors. With exception of a few sectors, the error correction mechanism adequately captures the short-term and long-term dynamics as indicated by the low LM-values. The R^2 ranges from 0.29 to 0.88, which is generally satisfactory. Notice that the regression diagnostics indicate modelling problems only for government institutions, semi-government institutions and TNO.

There are about as many sectors with a long-term elasticity which is smaller than the short-term elasticity, as there are sectors with the reverse pattern. At the sector level, the short-term elasticities vary between 0.23 and 1.35, while the long-term elasticities range from 0.31 to 1.14. At the aggregate level, the short-term elasticity is 0.47 and the long-term elasticity is 0.50. Hence the short-term effect and the long-term effect of R&D expenditure on R&D employment are about the same size at this level.

Small short-term elasticities are found for government institutions (0.23), university-affiliated institutions (0.32), PNPs (0.36) and the rubber and synthetic industry (0.36), indicating a modest impact of R&D expenditure on R&D employment on the short run. Small long-term elasticities are found for metal industries (0.31), food and beverage (0.34), chemicals and pharmaceuticals (0.36) and the textile, clothing and leather industry (0.36). Increased R&D expenditure may have a small long-term effect on R&D employment in these sectors. However, it should be mentioned the adjustment speed coefficients are difficult to estimate precisely for these sectors, except for metal industries. For chemicals and pharmaceuticals for example, the short-term elasticity is 0.59. Hence increased R&D expenditure in this sector will lead to a decent increase in R&D employment in the short-run, while the return to the lower long-run equilibrium level may very slow, as the estimated adjustment speed coefficient is not significantly different from zero.

The largest short-term elasticity is found for TNO (1.35). Large short-term and long-term elasticities are found for construction and installation (1.07 resp. 1.09), semi-government institutions (1.07 resp. 1.14) and universities (1.30 resp. 1.01). For these sectors, R&D expenditure has a large effect on R&D employment both in the short and the long run. Large R&D expenditure elasticities of R&D employment may reflect both demand and supply conditions. On the demand side, a sector may be labour-intensive with respect to R&D activities. On the supply side, R&D workers may have a high wage elasticity. Both explanations seem to play a role here: for universities and construction and installation we have already found large wage elasticities of supply (both short-term and long-term) and large long-term R&D expenditure elasticities of wages. The wage elasticities of supply and the R&D expenditure elasticities of wages for semi-government institutions are not exceptionally high, but large enough to cause a high sensitivity of R&D employment to R&D expenditure.

Table 3: R&D expenditure elasticities of R&D employment

sector	short-term elasticity "	adjustment speed (	LM	R^2	long-term elasticity $
Metal industries	0.44* (0.11)	-0.83* (0.20)	1.61	0.60	0.31
Chemicals and pharmaceuticals	0.59* (0.13)	-0.27 (0.19)	0.13	0.64	0.36
Food and beverage industry	0.90* (0.09)	-0.14 (0.11)	0.14	0.88	0.34
Rubber and synthetic industry	0.36* (0.07)	-0.58* (0.25)	0.48	0.57	0.44
Timber, furniture, paper and graphic industries	0.85* (0.10)	-0.51* (0.18)	1.52	0.84	0.82
Textile, clothing and leather industries	0.48* (0.15)	-0.55 (0.39)	0.12	0.48	0.36
Building materials	0.47* (0.11)	-0.72* (0.26)	0.58	0.58	0.43
Transport, communication and commercial services	0.80* (0.19)	-0.38 (0.24)	1.33	0.58	0.64
Agriculture and fisheries	0.73* (0.10)	-0.24 (0.19)	0.25	0.75	0.78
Construction and installation	1.07* (0.13)	-0.27 (0.22)	0.10	0.82	1.09
Electricity, gas and water	0.40* (0.13)	-0.96* (0.23)	0.87	0.59	0.44
Research enterprises	0.61* (0.10)	-0.07 (0.13)	0.25	0.68	0.82
Other industry	0.52* (0.08)	-0.32 (0.22)	2.32	0.73	0.86
Universities	1.30* (0.21)	-0.99* (0.21)	0.21	0.74	1.01
Government institutions	0.23 (0.18) -0.05 (0.18)	-0.18 (0.14)	0.02	0.29	0.40
Semi-government institutions	1.07* (0.38)	-0.94* (0.15)	17.67*	0.70	1.14
TNO	1.35* (0.51)	-1.08* (0.09)	18.42*	0.90	0.80
PNP	0.36* (0.06)	-0.44* (0.19)	0.21	0.67	0.52
University-affiliated institutions	0.32* (0.08) -0.05 (0.09)	-0.30* (0.09)	2.88	0.76	0.37
All sectors	0.47* (0.11)	-0.51* (0.19)	0.07	0.57	0.50

Estimation method: OLS, standard errors between brackets, asterisk denotes 5% significance
LM: Breusch-Godfrey Lagrange Multiplier test for first order serial correlation, asterisk denotes 5% significance

The results from table 1-3 are compiled in table 4. We may summarize this chapter on the Dutch labour market for R&D workers as follows.

At the aggregate level, we find cointegrating relationships between wages and R&D expenditure, between R&D employment and instrumented wages and between R&D employment and R&D expenditure. These relationships allow us to obtain logically consistent estimates of short-term and long-term elasticities of three types: R&D expenditure elasticities of wages, wage elasticities of the supply of R&D workers and R&D expenditure elasticities of R&D employment. The estimated adjustment speed coefficients in the error correction mechanisms from which the elasticities are estimated are all significant, indicating the empirical relevance of the long-term elasticities. The short-term and long-term R&D expenditure elasticities of R&D employment are about the same size: 0.50 and 0.47. These elasticities reflect both demand and supply conditions, which can be disentangled by the other two types of elasticities. The demand side is reflected by the R&D expenditure elasticities of wages. The short-term elasticity (0.52) is larger than the long-term elasticity (0.38), indicating that R&D expenditure has a short-term effect on wages with a smaller long-term effect. The supply side is represented by the wage elasticities of the supply of R&D workers. Here the short-term elasticity (0.96) is smaller than the long-term elasticity (1.20), implying that wage increases do have an effect in the short run, but the additional long run effect is larger. The following picture of the dynamics of the labour market for R&D workers therefore emerges from the elasticities. In the short-run, an increase in R&D expenditure has a strong effect wages, while the supply of R&D workers is still moderately sensitive to the wage rise. In the long run, the effect of R&D expenditure on wages dampens, but at the same time the sensitivity of the supply of R&D workers increases. As a net result, the effect on R&D employment is about the same size in the short and the long run. The strong short-run demand effect is weakened by the relative insensitivity of supply in the short run, while the moderate long-run demand effect is strengthened by the relative sensitivity of supply in the long run.

At the sectoral level, the cointegrating relationships are often weaker. For only 4 out of 19 sectors the modelling results are of the same quality as at the aggregate level, i.e. cointegrating relationships between the three variables and significant adjustment speed coefficients in each of the three error correction mechanisms: universities, PNPs, the rubber and synthetic industry and the building materials sector. Universities and PNPs both have R&D expenditure elasticities which are larger in the short run than in the long run, while the opposite holds for the wage elasticities of the supply of R&D workers. The net result for universities is a short-term R&D expenditure elasticity of R&D employment which is larger than its long-term counterpart. The net result for the PNPs is just the opposite. Notice also that the R&D expenditure elasticities of R&D employment for universities are much larger than for the aggregate. Both for universities and PNPs the dynamics of the labour market is similar to the aggregate dynamics, in the sense that demand effects are stronger in the short-term, while supply effects take more time. The opposite pattern holds for the rubber and synthetic industry and the building materials sector. The net result, expressed in terms of the R&D expenditure elasticities of R&D employment, is different for these two sectors. For the rubber and synthetic industry, the short-term elasticity is smaller than the long-term elasticity, while the reverse pattern holds for the building materials sector. It is clear that there is considerable variation in the "term structure of elasticities" across sectors, reflecting different demand and supply conditions.

Table 4: Summary of elasticities

	R&D expenditure elasticity of wages	wage elasticity of the supply of R&D workers	R&D expenditure elasticity of R&D employment
Metal industries	0.40* 0.35	1.11* 0.93*	0.44* 0.31*
Chemicals and pharmaceuticals	0.79* 0.52	0.65* 0.45*	0.59* 0.36
Food and beverage industry	1.06* 0.60	0.86* 0.48	0.90* 0.34
Rubber and synthetic industry	0.34* 0.54*	1.04* 0.94*	0.36* 0.44*
Timber, furniture, paper and graphic industries	0.82* 0.73	1.06* 1.02	0.85* 0.82*
Textile, clothing and leather industries	0.76* 0.69	0.63* 0.51	0.48* 0.36
Building materials	0.56* 0.64*	0.85* 0.69*	0.47* 0.43*
Transport, communication and commercial services	0.90* 0.47	0.96* 1.04	0.80* 0.64
Agriculture and fisheries	0.82* 0.88	0.89* 0.93	0.73* 0.78
Construction and installation	0.98* 1.06*	1.08* 1.06	1.07* 1.09
Electricity, gas and water	0.99* 0.84	0.37* 0.49*	0.40* 0.44*
Research enterprises	0.76* 0.97	0.85* 1.06	0.61* 0.82
Other industry	0.85* 0.93*	0.63* 0.96	0.52* 0.86
Universities	1.08* 0.47*	1.19* 1.74*	1.30* 1.01*
Government institutions	0.53* 0.98	1.05* 1.08	0.23 0.40
Semi-government institutions	0.85* 0.74*	0.89* 1.02	1.07* 1.14*
TNO	1.25* 0.81*	0.98* 0.95	1.35* 0.80*
PNP	0.60* 0.52*	0.58* 0.85*	0.36* 0.52*
University-affiliated institutions	0.43 0.98	1.13* 1.01*	0.32* 0.37*
All sectors	0.52* 0.38*	0.96* 1.20*	0.47* 0.50*

Short-term elasticity in upper part of each cell; asterisk denotes significance at 5% level of elasticity.
Lomg-term elasticity in lower part of each cell; sterisk denotes significance at 5% level of adjustment speed coefficient.

In the short run (i.e. within one year), a 1.0% increase in real R&D spending, leads to a 0.5% increase in R&D employment of R&D workers (in full-time equivalents) and a rise in the real gross wages of R&D workers of 0.5%. In other words, about half of the increase in R&D spending actually translates into an increase in knowledge activities, as measured by the FTE employment of R&D workers. The other half ends up as higher rewards for the human capital of R&D workers.

In the long run, keeping the real R&D expenditure fixed at the increased level, will lead to a lasting 0.5% increase of R&D employment and a permanent 0.4% increase in wages. Hence the effect of R&D spending on knowledge activities is fully realized within one year, while the wage effect shows a slight reduction over the following years. This pattern occurs because the short-term wage elasticity of the supply of R&D workers (in full-time equivalents) is smaller than the long-term elasticity, reflecting the considerable stock of human capital that is embodied in knowledge workers. A 1.0% increase in wages will increase the supply of R&D workers (in full-time equivalents) by 1.0% in the short run and by 1.2% in the long run..

However, the results also show considerable variation across different sectors of the economy. Especially worrying are the government institutions, where a 1.0% increase in R&D spending does not seem to have any effect on knowledge activities in the short run, while the expected long-run effect of 0.4% may be reached very slowly. It is difficult to give explanations from a demand side or a supply side perspective from the elasticities shown in table 1 and 2. However, remember that these tabulated elasticities were based on a restricted version of equation (3.4), where we dropped the constant term to obtain positive long-term R&D expenditure elasticities of wages. Estimation results based on the unrestricted version indicate that on the demand side, there seems to be a perverse effect of R&D expenditure on wages in the long run, while the short-run effect is negligible. On the supply side, there seems to be no effect of wages on the supply of R&D workers.

On the other side of the spectrum, there are also sectors of the Dutch economy where R&D expenditure leads to strong increases in knowledge actvities. A sustained 1.0% increase in R&D spending in construction and installation, universities and semi-government institutions leads to a lasting increase in knowledge activities of more than 1.0%. For the construction and installation sector both demand and supply conditions are responsible, as the R&D expenditure elasticities of wages and the wage elasticities of supply are large, both in the short run and the long run. In the case of universities and semi-government institutions, the short-run result is equally determined by demand and supply conditions. In the long run however, the wage elasticity of supply seems to make the largest contribution.

5. Conclusion

The most valuable source of information on R&D workers in the Netherlands is the R&D Survey of Statistics Netherlands. At the aggregate level, we find cointegrating relationships between wages and R&D expenditure, between R&D employment and instrumented wages and between R&D employment and R&D expenditure. These relationships allow us to obtain logically consistent estimates of short-term and long-term elasticities of three types: R&D expenditure elasticities of wages, wage elasticities of the supply of R&D workers and R&D expenditure elasticities of R&D employment. The estimated adjustment speed coefficients in the error correction mechanisms from which the elasticities are estimated are all significant, indicating the empirical relevance of the long-term elasticities. The short-term and long-term R&D expenditure elasticities of R&D employment are about the same size: 0.50 and 0.47. These elasticities reflect both demand and supply conditions, which can be disentangled by the other two types of elasticities. The demand side is reflected by the R&D expenditure elasticities of wages. The short-term elasticity (0.52) is larger than the long-term elasticity (0.38), indicating that R&D expenditure has a short-term effect on wages with a smaller long-term effect. The supply side is represented by the wage elasticities of the supply of R&D workers. Here the short-term elasticity (0.96) is smaller than the long-term elasticity (1.20), implying that a permanent wage increase does have an effect in the short run, but the additional long run effect is larger. The following picture of the dynamics of the labour market for R&D workers therefore emerges from the elasticities. In the short-run, an increase in R&D expenditure has a strong effect wages, while the supply of R&D workers is still moderately sensitive to the wage rise. In the long run, the effect of R&D expenditure on wages dampens, but at the same time the sensitivity of the supply of R&D workers increases. As a net result, the effect on R&D employment is about the same size in the short and the long run. The strong short-run demand effect is weakened by the relative insensitivity of supply in the short run, while the moderate long-run demand effect is strengthened by the relative sensitivity of supply in the long run.

The economic implications of the estimated elasticities are as follows. In the short run (i.e. within one year), a 1.0% increase in real R&D spending, leads to a 0.5% increase in R&D employment of R&D workers (in full-time equivalents) and a rise in the real gross wages of R&D workers of 0.5%. In other words, about half of the increase in R&D spending actually translates into an increase in knowledge activities, as measured by the FTE employment of R&D workers. The other half ends up as higher rewards for the human capital of R&D workers. In the long run, keeping the real R&D expenditure fixed at the increased level, will lead to a lasting 0.5% increase of R&D employment and a permanent 0.4% increase in wages. Hence the effect of R&D spending on knowledge activities is fully realized within one year, while the wage effect shows a slight reduction over the following years. This pattern occurs because the short-term wage elasticity of the supply of R&D workers (in full-time equivalents) is smaller than the long-term elasticity, reflecting the considerable stock of human capital that is embodied in knowledge workers. A 1.0% increase in wages will increase the supply of R&D workers (in full-time equivalents) by 1.0% in the short run and by 1.2% in the long run.

The more detailed sector data in the R&D Survey of Statistics Netherlands also show interesting differences between sectors, resulting from considerable variation in the "term structure of elasticities" across sectors, reflecting different demand and supply conditions. For government institutions, a 1.0% increase in R&D spending seems to have a very minor effect on knowledge activities in the short run, while the expected long-run effect of 0.4% is reached very slowly. There are also sectors of the Dutch economy where R&D expenditure leads to strong increases in knowledge actvities. A sustained 1.0% increase in R&D spending in construction and installation, universities and semi-government institutions leads to a lasting increase in knowledge activities of more than 1.0%. For the construction and installation sector both demand and supply conditions are responsible, as the R&D expenditure elasticities of wages and the wage elasticities of supply are large, both in the short run and the long run. In the case of universities and semi-government institutions, the short-run result is equally determined by demand and supply conditions. In the long run however, the wage elasticity of supply seems to make the largest contribution.

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