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**CAPITAL-SKILL COMPLEMENTARITY AND INEQUALITY IN
SWEDEN**

by

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Capital-Skill Complementarity and Inequality in Sweden*

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Abstract

Income inequality increased in Sweden during the 1980's and 90's as did the returns to higher education. The main conclusion of this study is that increased income inequality between high and low skilled workers is demand driven and is due to the presence of capital-skill complementarity in production. Increased investments in new, more efficient capital equipment, together with a slowdown in the growth rate of skilled labor, have raised the ratio of effective capital inputs per skilled worker, which, in turn, has increased the relative demand (and market return) for skilled labor through the capital-skill complementarity mechanism.

Keywords: capital-skill complementarity, inequality, relative wages, skill premium, university wage premium.

JEL: J31

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1 Introduction

Income inequality increased in Sweden during the 1980's and 90's. Between 1981 and 2000, the aggregate P90/P10 ratio of logged wages rose by 18 percent.¹ It rose by 26 percent for men and by 30 percent for private sector employees (le Grand et al., 2001). Similar rises in wage inequality have been experienced in many OECD countries during this time period. These changes in wage differentials appear to have been driven by increases in wages in the upper end of the wage distribution (Katz and Autor, 1999; le Grand et al., 2001). This has led many researchers to focus their attention on the contemporaneous rise in the economic returns to higher education.²

In Sweden, the university wage premium for full-time workers estimated using the Swedish Level of Living Survey rose by 13 percent between 1991 and 2000.³ Statistics Sweden reports that the university wage premium for white-collar males in Swedish industry rose by 20 percent between 1983 and 1999, while the university wage premium for all men in the Swedish private sector increased by even more (Davis, 1992; SCB1).⁴ At the same time, the supply of university educated workers was growing. The number of workers with a university degree increased by 20 percent between 1983 and 1999 (SCB6). Together, these facts leave us with the following question: Why has the university wage premium risen in Sweden during a period of substantial growth in the relative supply of university educated workers?

This question will be examined using a neoclassical growth framework based on recent work by Krusell, Ohanian, Ríos-Rull and Violante (2000) (hereafter KORV). Their influential study proposes an explanation of the even more dramatic rise in the university wage premium experienced in the United States during this time. They argue that the falling relative price of capital equipment (due to equipment-

¹P90 and P10 stand for the 90th and 10th percentiles of the distribution of logged wages.

²See Katz and Autor (1999) for an overview of this literature.

³Author's estimate as reported in Section 3.

⁴The rise in the Swedish university wage premium is documented and discussed in more detail in Gustavsson (2004).

specific technological change) has led to increased investment and, subsequently, to an increase in the ratio of capital equipment per skilled worker in the economy. This raises the market return to higher education (which is used as a proxy for skills) through the capital-skill complementarity mechanism.⁵

The purpose of this study is to determine whether or not the capital-skill complementarity mechanism can be used to help explain rising income inequality in Sweden. This will be done by applying the KORV model to Swedish data.⁶

The Swedish experience is an especially interesting test case for the KORV model. The historical development of the Swedish skill premium differs significantly from that of the US skill premium. In particular, Sweden experienced an unprecedented drive towards wage equality between 1967 and 1983. Differences in labor market institutions also make Sweden an excellent (albeit tough) test case for the theory and model presented in KORV. Since institutional models and explanations dominate the Swedish debate on relative wage determination,⁷ our a priori belief should be that a simple, market oriented model will not be able to explain movements in the skill premium in Sweden: at least not very well.

What we find instead, is that the KORV model can account quite well for movements in the Swedish skill premium. The main conclusion of this study is that increased income inequality between high and low skilled workers is demand driven and is due to the presence of capital-skill complementarity in production. Since 1985, increased investments in new, more efficient capital equipment, together with a slowdown in the growth rate of skilled labor, have raised the ratio of effective capital inputs per skilled worker, which, in turn, has increased the relative demand (and market return) for skilled labor through the capital-skill complementarity mecha-

⁵Griliches (1969) formalized the idea of capital-skill complementarity and showed it to be a key feature of modern production technology.

⁶Batista (2002) applied the KORV model to Portuguese data and found that the capital-skill complementarity mechanism could explain a significant share of the changes in the skill premium in Portugal.

⁷See e.g. Flam (1987), Edin and Holmlund (1995), Hibbs and Locking (1996), Edin and Topel (1997), Arai and Kjellström (1999), Lindquist (2000).

nism.⁸

Rising wage inequality between high and low skilled workers has received considerable attention in the Anglo-American literature. Notable studies include Bound and Johnson (1992), Katz and Murphy (1992) and, more recently, KORV. In contrast, the Swedish (and continental European) debate has paid less attention to rising wage inequality and focused more on the large drop in demand for low skilled workers and subsequent unemployment among the low skilled (see e.g. Nickell and Bell, 1995; and for Sweden, see e.g. Mellander, 1999; Hansson, 2000; Anderton et al. 2002). The arguments and explanations within this debate are very similar to those found in the Anglo-American literature.

These explanations can be placed into three (not necessarily exclusive) categories; *supply effects*, *demand effects* and *institutional effects*. Institutional effects include a fall in the union wage premium and changes in wage-bargaining frameworks. Supply effects include both changes in the quantity of skilled labor and in (unobservable) labor quality.⁹ Demand effects are attributed to increasing trade with low wage countries (which includes outsourcing of low-skilled production tasks),¹⁰ to trade induced sector-biased technological change,¹¹ and to skill-biased technological change.¹² The KORV model used in this paper provides us with a specific, economic interpretation of skill-biased technological change, as well as a hypothesis which can be tested using observable factor quantities and prices. KORV argue that the residual trend in labor productivity used by many authors to explain the increase in the skill premium is, in fact, a proxy for the omitted capital-skill complementarity variable.¹³

⁸This finding is similar to Hansson's (2000) conclusion that the accumulation of physical and knowledge capital increased the demand for skilled labor in Swedish manufacturing during the late 1980's and early 1990's.

⁹For Sweden, see Edin and Holmlund (1995) and Mellander (1999).

¹⁰For empirical studies using Swedish data, see e.g. Hansson (2000) and Anderton et al. (2002).

¹¹For a multi-sector, applied general equilibrium model of a small open economy, see De Santis (2002, 2003).

¹²For Sweden, see Mellander (1999), Hansson (2000) and Anderton et al. (2002).

¹³Bound and Johnson (1992) evaluate the evidence concerning the impact of these different effects on the wage-structure in the United States during the 1980's. Their analysis, "points strongly to the

The remainder of this study is outlined as follows. The KORV model is presented in Section 2. Then, in Section 3, the Swedish data are examined in the light of this model. This initial examination shows us that the data are consistent with the capital-skill complementarity hypothesis.

The quantitative analysis and results are presented in Section 4. First, the full econometric model is presented. Then, the main parameters of interest in the benchmark model are estimated using a simulated pseudo-maximum likelihood method. These parameters are used in a decomposition experiment which demonstrates the importance of the capital-skill complementarity mechanism for explaining rising income inequality in Sweden.

This is followed by two alternative experiments. The first experiment includes a trend in the relative efficiency of skilled labor. The second includes a trend in the efficiency of capital equipment. Allowing for unobservable trends improves the fit of the model and delivers some interesting results. It does not, however, change the main conclusion which arose from the analysis of the benchmark model. Increased income inequality between high and low skilled workers is still demand driven and is due to the presence of capital-skill complementarity in production.

Section 5 concludes.

2 The Model

The KORV model is a two sector model of the production side of the economy. One sector produces new capital equipment, x_{et} , and the other produces consumption

conclusion that the principal reason for the increase in wage differentials by educational attainment and the decrease in the gender differential is a combination of skilled-labor-biased technological change and changes in unmeasured labor quality" (p. 389). Katz and Murphy (1992) report similar results. As such, the leading explanations of growth in the skill premium in the United States during the 1980's and '90's have relied upon a residual trend in labor productivity, which has been labeled as either skilled-biased technological change or as increases in unmeasured labor quality.

goods, c_t , and new capital structures, x_{st}

$$x_{et} = q_t a_t G(k_{st}^e, k_{et}^e, u_t^e, s_t^e) \quad (1)$$

$$c_t + x_{st} = a_t G(k_{st}^c, k_{et}^c, u_t^c, s_t^c). \quad (2)$$

Both sectors have access to a common production function, $G(\cdot)$, which is homogeneous of degree one and use capital structures, k_{st} , capital equipment, k_{et} , skilled labor, s_t , and unskilled labor, u_t , to produce output. Both sectors have access to a common technology, a_t . The equipment producing sector also has access to an equipment-specific technology, q_t , which represents the embodiment of IT advancements.

Assuming perfect competition, aggregate output (in terms of consumption units) can be written as

$$y_t = c_t + x_{st} + \frac{x_{et}}{q_t} = a_t G(k_{st}, k_{et}, u_t, s_t). \quad (3)$$

The evolution of capital is given by

$$k_{s,t+1} = (1 - \delta_s) k_{st} + x_{st} \quad (4)$$

$$k_{e,t+1} = (1 - \delta_e) k_{et} + x_{et}, \quad (5)$$

where δ_s , and δ_e , are the depreciation rates for structures and equipment, respectively.

The KORV model uses a four-factor, constant returns to scale production function which is Cobb-Douglas over structures and a CES function of the three remaining factors of production

$$G(k_{st}, k_{et}, u_t, s_t) = k_{st}^\alpha \left[\mu u_t^\sigma + (1 - \mu) (\lambda k_{et}^\rho + (1 - \lambda) s_t^\rho)^{\frac{\sigma}{\rho}} \right]^{\frac{1-\alpha}{\sigma}}, \quad (6)$$

where $\alpha, \mu, \lambda \in (0, 1)$ and $\sigma, \rho \in (-\infty, 1)$. The CES parameter weights on unskilled

labor and equipment are given by μ and λ , respectively. In equilibrium, the income share of structures will be equal to the technological parameter α . The two key substitution parameters are σ and ρ .

The elasticity of substitution between equipment and skilled labor, S_{kes} , is equal to $1/(1 - \rho)$. The elasticity of substitution between equipment and unskilled labor, S_{keu} , and the elasticity of substitution between skilled and unskilled labor, S_{su} , are both equal to $1/(1 - \sigma)$. The hypothesis of capital-skill complementarity implies $\sigma > \rho$.

Inputs of capital equipment and labor are measured in efficiency units. Skilled labor inputs are defined as $s_t \equiv \psi_{st}n_{st}h_{st}$. Unskilled labor inputs are defined as $u_t \equiv \psi_{ut}n_{ut}h_{ut}$. The number of each type of worker is given by n_{it} and h_{it} is the average number of hours worked by each type of worker. Inputs of capital equipment are defined as $k_{et} \equiv \psi_{et}\tilde{k}_{et}$, where \tilde{k}_{et} is the stock of capital equipment unadjusted for changes in quality.¹⁴

The efficiency of a unit of factor input $i \in \{u, s, e\}$ is given by the exogenous index ψ_{it} . The logs of these efficiency indices, $\log(\psi_{it}) \equiv \varphi_{it}$, are modeled as trend stationary processes¹⁵

$$\varphi_{it} = \varphi_{i0} + \gamma_i t + \varpi_{it}, \quad (7)$$

where the ϖ_{it} 's are normally distributed *i.i.d.* shocks to the efficiency of capital equipment and labor with mean zero and covariance matrix $\mathbf{\Omega}$. Each type i input has an initial level of efficiency given by φ_{i0} and the efficiency of each type i input grows at rate γ_i . Together, Equations 6 and 7 give us a fully specified, stochastic production function.

¹⁴Allowing for a trend in the efficiency of capital equipment is a slight modification of the original KORV model. They have a quality adjusted measure of capital equipment, k_{et} . No such measure exists for Sweden. Instead, an unadjusted measure of capital equipment is used, \tilde{k}_{et} . Including ψ_{et} in the model, allows us to examine the potential effect of increasing equipment efficiency on the skill premium. This will be done in Section 4.

¹⁵The implications of this trend stationary specification and the potential consequences of alternative specifications are discussed in Ohanian, Violante, Krusell and Ríos-Rull (2000) which is a technical companion paper to KORV.

The skill premium in the KORV model is defined as the ratio of skilled to unskilled wages, which, under the assumption of perfect competition, is equal to the ratio of their marginal products

$$\frac{w_{st}}{w_{ut}} = \frac{(1-\mu)(1-\lambda)}{\mu} \underbrace{\left[\lambda \left(\frac{\psi_{et} \tilde{k}_{et}}{s_t} \right)^\rho + (1-\lambda) \right]^{\frac{\sigma-\rho}{\rho}}}_{\text{CSC-effect}} \underbrace{\left(\frac{n_{ut} h_{ut}}{n_{st} h_{st}} \right)^{1-\sigma}}_{\text{RQ-effect}} \underbrace{\left(\frac{\psi_{st}}{\psi_{ut}} \right)^\sigma}_{\text{RE-effect}}. \quad (8)$$

Equation 8 expresses the skill premium as a function of relative factor inputs. It provides us with a way of using the KORV model to understand how changes in factor inputs affect the skill premium by decomposing the skill premium into its fundamental components; the *relative quantity effect*, the *relative efficiency effect*, and the *capital-skill complementarity effect*.

The relative quantity (RQ) effect says that when skilled hours grow at a faster rate than unskilled hours the skill premium will fall (recall that $\sigma < 1$). This is the same as Edin and Holmlund's (1995) supply-side effect.

The relative efficiency (RE) effect depends on the sign of the substitution parameter, σ . If $\sigma > 0$, then the elasticity of substitution between the two types of labor is greater than one which means that they are substitutes for one another in the production process. In this case, when the efficiency of skilled labor grows faster than that of unskilled labor, the skill premium will rise. It is this kind of (inherently unobservable) trend which Bound and Johnson (1992) and Katz and Murphy (1992) used to explain movements in the skill premium.¹⁶

The third effect is the capital-skill complementarity (CSC) effect. If skilled labor and capital equipment are complementary factors of production, i.e. if $\sigma > \rho$, then increases in the quantity and/or quality of the one will increase the marginal productivity of the other. So, as the stock of capital increases and as the quality of

¹⁶The relative efficiency effect is modeled here as a supply-side effect, i.e. as unobservable changes in the quality of skilled labor relative to unskilled labor. In other settings, this type of unobservable trend has been modeled on the demand-side. In these cases, it is often labeled as skill-biased technological change.

new investments improves, the wage for skilled workers will *ceteris paribus* increase.¹⁷

3 The Data

The KORV model will be estimated using annual Swedish data from 1970 to 1999.¹⁸ The measure of the skill premium, w_{st}/w_{ut} , used in this study is the university wage premium for white-collar men in mining, manufacturing and construction. This series will act as a proxy for the return to skills for all workers in the Swedish economy, since an equivalent, aggregate measure does not exist.

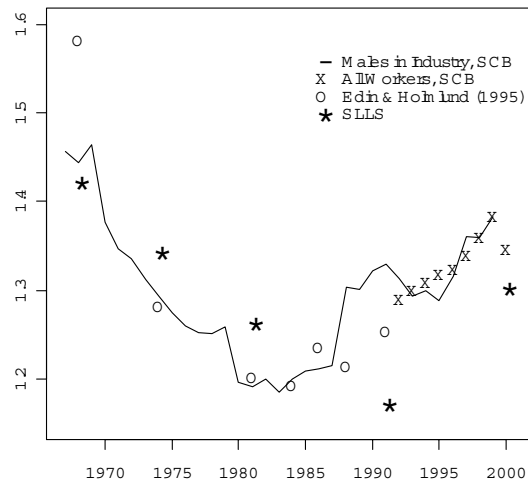


Figure 1: The University Wage Premium in Sweden, 1967-2000.

In Figure 1, we see that the skill premium for male employees in Swedish industry fell by 27 percent between 1967 and 1983 and then rose by 20 percent between 1983 and 1999. Time series data from Statistics Sweden (SCB) show a similar rise for all workers during the 1990's. Using panel data, Edin and Holmlund (1995) report

¹⁷Studies by Bergström and Panas (1992), Machin and Van Reenen (1998), Mellander (1999), Hansson (2000) and Anderton et al. (2002) have all found capital-skill complementarity to be present in the production process in Sweden.

¹⁸Details concerning data construction and sources can be found in Appendix A.

a fall in the university wage premium followed by a weak upturn during the mid 1980's.¹⁹ Gustavsson (2004) documents a steady increase in the university wage premium beginning in the early 1980's. Estimates using the Swedish Level of Living Survey (SLLS) are also reported in Figure 1.²⁰ On the whole, the data in Figure 1 show us that the skill premium used in this paper may, in fact, be a reasonable proxy for trends in the university wage premium for all workers.²¹

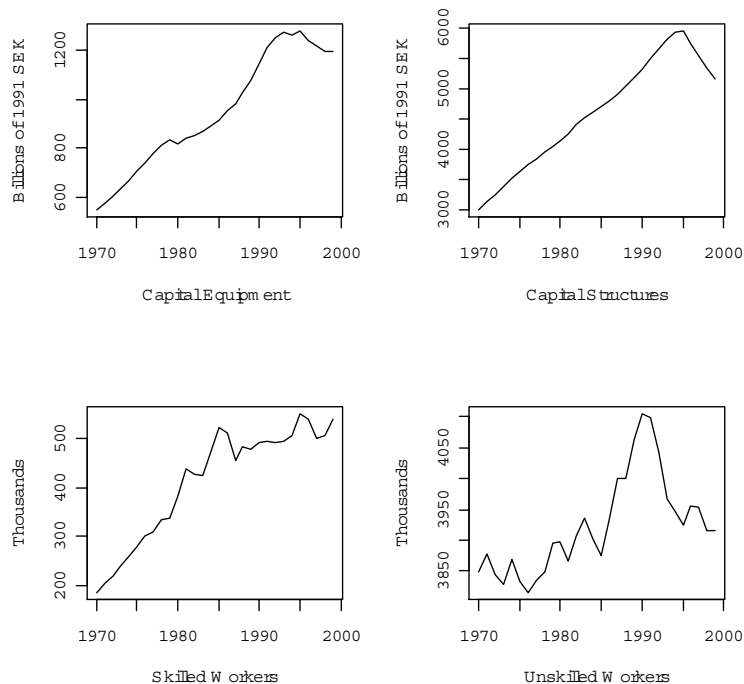


Figure 2: Aggregate factor Inputs, 1970-1999.

¹⁹Edin and Holmlund (1995) estimate the university wage premium using both the Swedish Level of Living Survey and the Swedish Household Survey.

²⁰These estimates were carried out by the author. First, the results of Arai and Kjellström (2001) and le Grand et al. (2001) were replicated. Then, the variable for years of schooling was replaced with the variable for educational categories, using high school as the reference category.

²¹This is not, however, an uncontroversial assumption. The time series data are not standardized for differences in the age structure of the two categories of workers. The time series data may also exaggerate the increase in wage inequality. There is an extraordinarily large jump in the time series occurring in 1987 and Statistics Sweden does not report any obvious candidate for this jump (i.e. there is no mention of any particular definitional changes, data collection problems, etc.). They did, however, revise their measure in 2000. This revision lowered the university wage premium (for that year), moving it closer to the author's estimate from the SLLS shown in Figure 1.

Figure 2 shows aggregate time series of capital equipment, \tilde{k}_{et} , capital structures, k_{st} , the number of skilled workers, n_{st} , and the number of unskilled workers, n_{ut} . Average hours worked by skilled and unskilled workers, h_{it} , fluctuate quite a bit at business cycle frequencies, but show no tendency to trend up or down between 1970 and 1999 (SCB5). Thus, the number of workers, n_{it} , is an appropriate measure of the long run, potential supply of both types of labor and h_{it} will be normalized to one in the empirical analysis. Furthermore, the number of unskilled workers includes those who are unemployed as well as latent job seekers. This is done in order to insure that n_{ut} can be treated as the exogenous, long run supply of unskilled labor in our estimations.²²

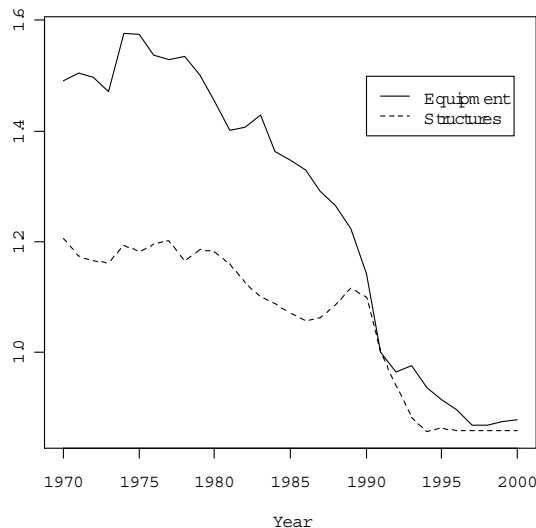


Figure 3: Relative Price Indices for Equipment and Structures, 1970-2000.

Both equipment and structures have been deflated using the appropriate price index.²³ The prices of equipment and structures relative to consumption are shown in Figure 3. The relative price of structures is nearly constant until about 1990.

²²See Appendix B for a more thorough discussion of this topic.

²³The price index for equipment used in KORV is quality adjusted. Unfortunately, the same kind of quality adjusted price index does not exist for Sweden. However, a model with a trend in the efficiency of capital equipment, ψ_{et} , will be estimated in Section 4.

Between 1990 and 1994, the relative price of structures dropped dramatically; readjusting to a new, lower level in the aftermath of the Swedish banking and real estate crises. The relative price of equipment, on the other hand, has been decreasing steadily since 1974. KORV interpret a similar decline in the relative price of equipment in the United States as a proxy for equipment-specific technological change. In the KORV model, and in the empirical analysis in this paper, the relative price index of structures is set equal to one, while q_t is the relative price index for equipment shown in Figure 3.

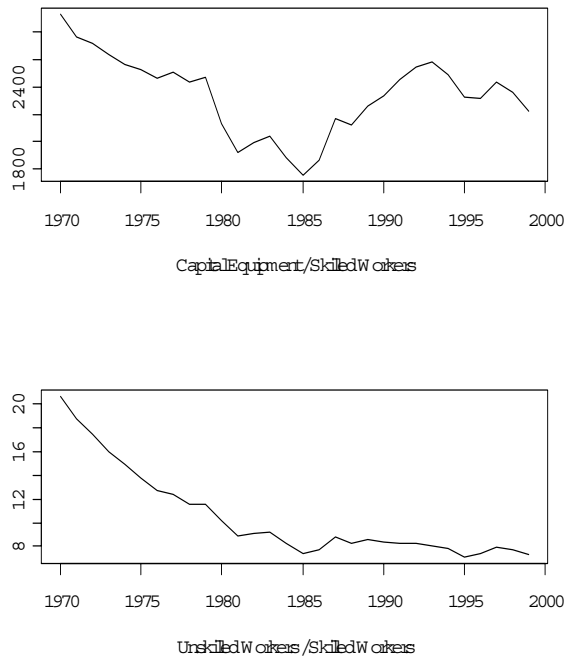


Figure 4: Relative Factor Inputs, 1970-1999.

Re-examining Equation 8, we see that the skill premium can be affected by changes in both the ratio of unskilled to skilled labor and by changes in the ratio of capital equipment per skilled worker. If we examine the graphs of these factor input ratios in Figure 4, we see that there has, in fact, been an increase in the relative supply of skilled labor, particularly before 1985, after which the growth in

skilled labor stagnated. This would tend to support the supply-side hypothesis. But we also see a strong correlation (equal to 0.70) between the skill premium and the ratio of capital equipment per skilled worker. In Figure 4, we see that the ratio of capital equipment per skilled worker exhibits the same two trends as the skill premium: a falling trend after 1970 and a rising trend after 1985. Thus, a preliminary examination of the raw data supports the hypothesis of capital-skill complementarity as a potentially important factor behind movements in the skill premium.

4 The Quantitative Analysis

4.1 The Econometric Model

The econometric model consists of three structural equations which are derived from the profit maximizing conditions of the firm under the assumption of perfect competition. These three equations are; the labor share equation, the wage-bill ratio equation and the no arbitrage equation

$$\frac{w_{st}n_{st} + w_{ut}n_{ut}}{y_t} = lsh_t(\boldsymbol{\psi}_t, \mathbf{X}_t; \boldsymbol{\phi}) \quad (9)$$

$$\frac{w_{st}n_{st}}{w_{ut}n_{ut}} = wbr_t(\boldsymbol{\psi}_t, \mathbf{X}_t; \boldsymbol{\phi}) \quad (10)$$

$$(1 - \delta_s) + a_{t+1}G_{k_s}(\boldsymbol{\psi}_{t+1}, \mathbf{X}_{t+1}; \boldsymbol{\phi}) = E_t\left(\frac{q_t}{q_{t+1}}\right)(1 - \delta_e) + q_t a_{t+1}G_{k_e}(\boldsymbol{\psi}_{t+1}, \mathbf{X}_{t+1}; \boldsymbol{\phi}) \quad (11)$$

where $\boldsymbol{\psi}_t \equiv \{\psi_{ut}, \psi_{st}, \psi_{et}\}$ is the vector of efficiency indices, $\mathbf{X}_t \equiv \{k_{et}, k_{st}, n_{st}, n_{ut}\}$ is the vector of exogenous factor inputs,²⁴ E_t is the expectations operator, and $\boldsymbol{\phi} \equiv \{\delta_s, \delta_e, \alpha, \mu, \lambda, \sigma, \rho, \eta_e, \gamma_i, \varphi_{i0}, \Omega\}$ is the vector of model parameters. The parameter η_e is defined below.

Equation 9 is the labor Share equation. It has labor's share of income as its

²⁴Recall that h_{it} has been normalized to 1. See Section 3.

dependent variable. The right hand side of this equation is comprised of the theoretical counterpart from the model. Equation 10 is the wage-bill ratio equation, which has the ratio of the wage-bill for skilled to unskilled labor as its dependent variable and on the right hand side the theoretical counterpart from the model.

Equation 11 is a no arbitrage equation which acts as a proxy for the unobservable rental rates of capital equipment and capital structures. It equates the expected, future $(t+1)$ returns on investments in equipment and structures. The left hand side of this equation is the date $t+1$ return on investments in structures, which consists of two components. The first component, $(1 - \delta_s)$, is the share of undepreciated capital structures carried over from the previous period. The second component, $a_{t+1}G_{k_s}(\psi_{t+1}, \mathbf{X}_{t+1}; \phi)$, is the marginal product of capital structures. The right hand side of the equation is the date $t+1$ return on investments in equipment, which also consists of two components. The first component, $E_t(q_t/q_{t+1})(1 - \delta_e)$, is the share of undepreciated capital equipment carried over from the previous period multiplied by the expected rate of change in the relative price of capital equipment. The second component, $q_t a_{t+1}G_{k_e}(\psi_{t+1}, \mathbf{X}_{t+1}; \phi)$, is the marginal product of capital equipment.²⁵

The parameter vector ϕ in Equations 9-11 includes 20 parameters. Given the small sample size and the complications each additional parameter adds to the optimization routine used to estimate the model, it is appropriate to reduce the dimension of this vector. This can be done by calibrating several of the parameters in advance of the estimation procedure. The calibration process is discussed in detail in Appendix B. Table 1 summarizes the calibrated parameters. The remaining

²⁵There are four simplifying assumptions made in this no arbitrage equation all of which are addressed thoroughly in KORV and in Ohanian, Violante, Krusell and Ríos-Rull (2000), which is a technical companion paper to KORV. First, they assume that there is no risk premium, which means that we can ignore the covariance between consumption and returns in the estimation. Second, they assume that there is equal tax treatment of the two types of capital goods. Third, they replace the expression $E_t(q_t/q_{t+1})(1 - \delta_e)$ with $(1 - \delta_e)q_t/q_{t+1} + \varepsilon_t$, where ε_t is the *i.i.d.* forecast error, which is assumed to be normally distributed with mean zero and variance η_ε^2 , $\varepsilon_t \stackrel{i.i.d.}{\sim} N(0, \eta_\varepsilon^2)$. Fourth, they assume that a_{t+1} and φ_{it+1} are known when investment decisions are made. Thus, q_{t+1} is the only unknown.

parameters to be estimated are $\{\mu, \lambda, \sigma, \rho, \gamma_i, \varphi_{i0}\}$. The benchmark model has no trend, so $\gamma_s = \gamma_u = \gamma_e = 0$ and φ_{s0} is normalized to zero, while φ_{e0} is normalized to one.

Table 1: Predetermined Parameters in the Benchmark Model.

α	δ_e	δ_s	η_e	$\eta_{\omega_u} = \eta_{\omega_s}$	η_{ω_e}	$\eta_{\omega_{ij}}$	γ_s	γ_u	γ_e	φ_{s0}	φ_{e0}
0.1896	0.125	0.05	0.017	0.0185	0	0	0	0	0	0	1

4.2 Findings From the Benchmark Model

The model is estimated using a simulated pseudo-maximum likelihood method.²⁶ Estimates of the substitution parameters are reported in Table 2 (standard errors are in parentheses). The parameter estimates show that production is, in fact, characterized by strong capital-skill complementarity. The substitution parameter σ is positive and significantly larger than the negative substitution parameter ρ . These estimates confirm the findings of Bergström and Panas (1992), Machin and Van Reenen (1998), Mellander (1999), Hansson (2000) and Anderton et al. (2002).

Table 2: Parameter Estimates and Substitution Elasticities.

σ	ρ	$\mathbf{S}_{uke} = S_{us} = \frac{1}{1-\sigma}$	$\mathbf{S}_{ske} = \frac{1}{1-\rho}$
0.2873	-0.9344	1.40	0.52
(0.0097) ^a	(0.0179)		

a) Standard errors in parentheses.

The elasticity of substitution between unskilled labor and capital equipment, S_{uke} , is 1.40. This implies that they are substitutes for one another in the production process. The elasticity of substitution between skilled labor and capital equipment, S_{ske} , is 0.52, which implies that they are complementary factor inputs. Both estimates are well within the reasonable boundaries marked out in the empir-

²⁶See Appendix B for details.

ical literature reviewed in Hamermesh (1993).²⁷

Figure 5 shows us that the econometric model works well along all three dimensions. The no arbitrage condition is fulfilled (on average). The model wage-bill tracks the actual wage bill relatively closely and the average labor share of income in the model is equal to that found in the data.

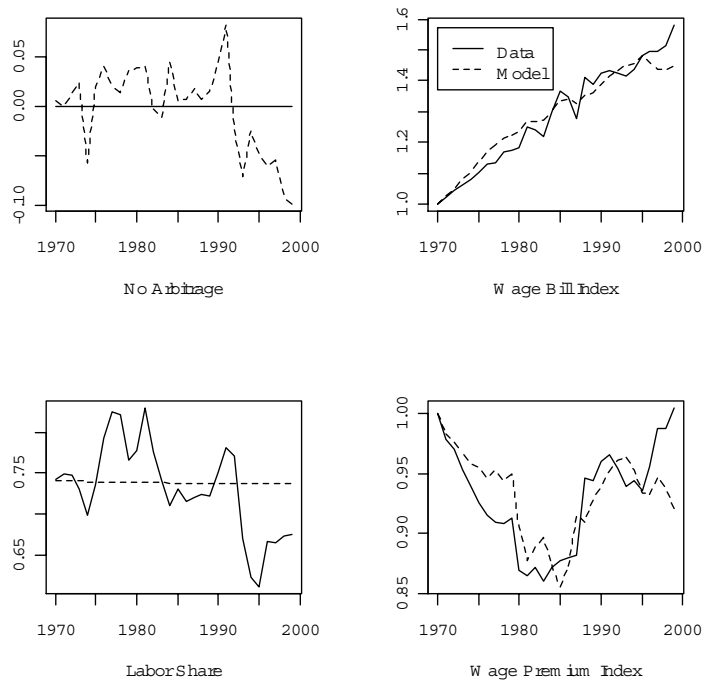


Figure 5: Results from the Benchmark Model.

The model skill premium is shown in the lower right panel of Figure 5. It matches the skill premium in the data quite well. It captures both of the major trends found in the data. The model produces a sharp downturn after 1970 and a sharp rise after 1985. Thus, we can conclude that the KORV model is able to predict movements in

²⁷KORV report estimates of $S_{uke} = 1.67$ and $S_{ske} = 0.67$ for the aggregate US economy. Lindquist (2001) reports estimates of $S_{uke} = 1.95$ and $S_{ske} = 0.73$ for Swedish Industry. Both KORV and Lindquist (2001) use hours worked as a measure of labor input, while this study uses the number of workers as a measure of labor inputs. The fact that the estimates in Table 2 are lower than the estimates reported by KORV and Lindquist (2001) is probably because it is easier to substitute between hours and equipment than people and equipment.

the Swedish skill premium.²⁸ This is done using only observable data on quantities and prices of factor inputs.

Changes in the skill premium from the benchmark model can be decomposed into their two primary components; the capital-skill complementarity (CSC) effect and the relative quantity (RQ) effect. The results of this exercise are reported in Table 3. The capital-skill complementarity effect is clearly dominant and explains (on average) 63 percent of the changes in the model skill premium in Sweden between 1970 and 1999.²⁹

Table 3: Decomposition of Changes in the Model Skill Premium.

	s	u	k_e	Total
CSC-effect	31%	0	32%	63%
RQ-effect	30%	7%	0	37%
Total	61%	7%	32%	100%

The impact of an increase in the number of skilled workers on the skill premium is twofold in this model. It has a direct, negative effect through the relative quantity effect and a, perhaps, less obvious, negative impact through the capital-skill complementarity effect. Changes in capital equipment and unskilled labor each have only one channel through which they can effect the skill premium, the capital-skill complementarity effect and the relative quantity effect, respectively.

Each of these effects can be decomposed (exactly) into two components by setting the growth rate of one factor input to zero while allowing the other to move with the data. For example, the capital-skill complementarity effect can be decomposed into two components by first setting the growth rate of capital equipment to zero, while still allowing for growth in skilled labor. Then, set the growth rate of skilled labor to zero and allow for growth in capital equipment. A similar decomposition

²⁸The correlation between the skill premium in the data and the model skill premium is 0.73.

²⁹The importance of the CSC-effect is actually growing over time (see Figure 6).

can be made for the relative quantity effect by first setting the growth rate of skilled labor to zero and then by setting the growth rate of unskilled labor to zero.

Table 3 summarizes these results and shows us to what extent each factor input is responsible for changes in the skill premium and through which channel it affects the skill premium. On average, during the sample period from 1970 to 1999, 61 percent of the changes in the skill premium can be attributed to changes in the quantity of skilled labor. This impact on the skill premium was through two equally important channels, the capital-skill complementarity effect and the relative quantity effect. Changes in the capital stock account for 32 percent of the changes in the skill premium, while changes in the supply of unskilled labor was responsible for 7 percent of the changes in the skill premium.

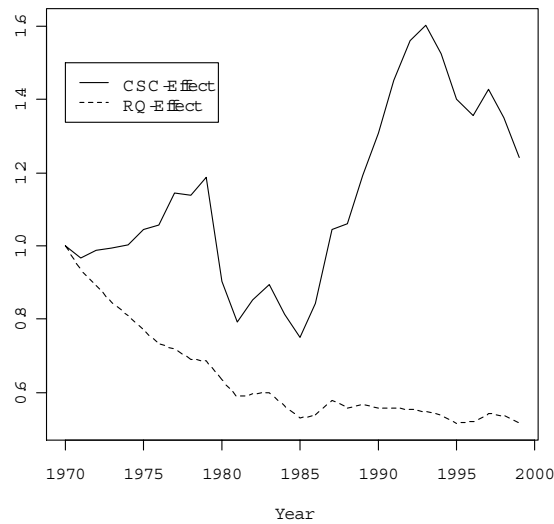


Figure 6: The Capital-Skill Complementarity Effect and the Relative Quantity Effect.

Figure 6 illustrates the cumulative impact of the capital-skill complementarity and relative quantity effects upon the skill premium in Sweden between 1970 and 1999. The relative quantity effect has had a significantly negative impact on the skill premium until the early 1980's. After which, it became more neutral. The capital-

skill complementarity effect has had a more varied impact on the skill premium. But, what is clear from Figure 6, is that the rise in labor income inequality beginning in the mid 1980's is demand driven and due entirely to the capital-skill complementarity mechanism.

4.3 Findings From the Model With an Unobservable Trend

In order to explore the residual labor productivity hypothesis of Katz and Murphy (1992) and Bound and Johnson (1992), the KORV model is reestimated allowing for a nonzero trend in the relative growth rate of the efficiency of skilled labor, $g_s \equiv \gamma_s - \gamma_u$, where γ_u is (still) normalized to zero.³⁰ This added element improves the model fit (see Figure 7).³¹ It also improves the model's ability to explain movements in the skill premium (see the lower right panel of Figure 7).³²

The new estimates of σ and ρ are quite similar to those from the benchmark model (compare the estimates in Table 4 with those in Table 2). The production process is still characterized by strong capital-skill complementarity. Second, the structural estimate of g_s obtained from the new model specification is actually negative, which tells us that the best solution to the structural model includes a decrease in the relative efficiency of skilled labor equal to 1 percent per year. This is, of course, not what Katz and Murphy (1992) or Bound and Johnson (1992) had in mind!³³ One way of rationalizing this negative trend in the relative efficiency of skilled labor would be to argue that the rapid expansion of the higher education system in Sweden during this time period resulted in lower educational standards

³⁰See Appendix B for important details concerning this estimation.

³¹In particular, it improves the fit of the wage bill equation, which, in turn, is closely related to the equation for the skill premium. This is, of course, a very sensible result given that the labor share of income and the no arbitrage condition do not trend, while the wage bill does.

³²The correlation between the skill premium in the data and the model skill premium is 0.92.

³³Running a Katz and Murphy (1992) style regression using the Swedish data results in an increase in the relative efficiency of skilled labor equal to 3.5 percent per year.

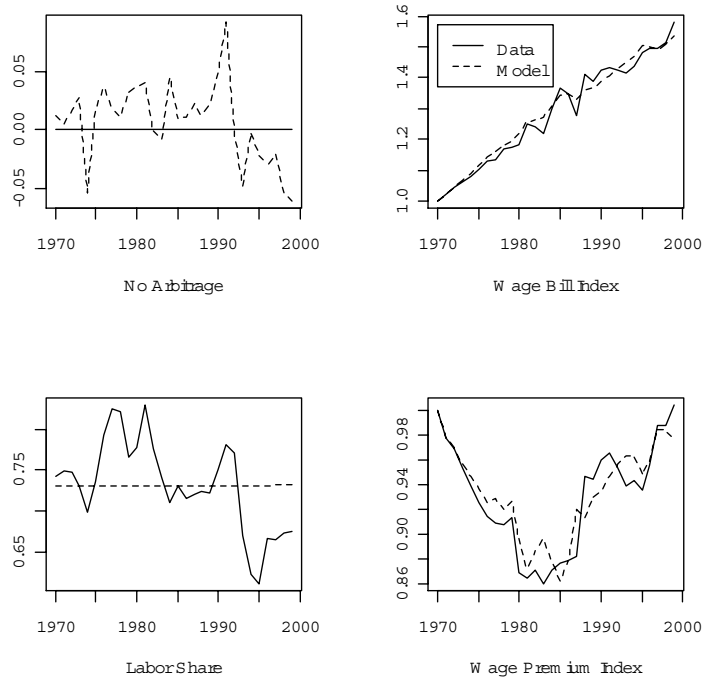


Figure 7: Results from the Model with an Unobservable Trend.

and/or the admission of lower quality students.³⁴

Table 4: Parameter Estimates and Substitution Elasticities.

\mathbf{g}_s	$\boldsymbol{\sigma}$	$\boldsymbol{\rho}$	$\mathbf{S}_{uk_e} = \frac{1}{1-\sigma}$	$\mathbf{S}_{sk_e} = \frac{1}{1-\rho}$
-0.01	0.3083	-0.9239	1.45	0.52
	(0.0030) ^a	(0.0405)		

a) Standard errors in parentheses.

This decline in the relative efficiency of skilled labor actually pushes the model skill premium up towards the end of the sample. This is made possible by the presence of capital-skill complementarity in the production process. When $\sigma > \rho$,

³⁴Arai and Kjellström (1999) also mention the possibility that falling returns to schooling in Sweden during the 1970's may, in part, be due to the lower quality of education during times of great expansion in the educational institutions.

the relative efficiency of skilled labor has two countervailing effects on the skill premium. First, it has a direct, negative impact through the relative efficiency effect. Second, it has an indirect, positive effect through the capital-skill complementarity effect, since it raises the stock of capital equipment per unit of skilled labor measured in efficiency units (reexamine Equation 8). Towards the end of the sample, the CSC-effect dominates, so that the fall in the relative efficiency of skilled labor leads to a higher demand (and market return) for skilled workers.

The results of the decomposition experiment are shown in Table 5. The inclusion of a trend in the relative efficiency of skilled labor decreases the importance of the CSC-effect and of changes in the stock of capital equipment. The cumulative impact of each of the three effects is shown in Figure 8.

Table 5: Decomposition of Changes in the Model Skill Premium ($g_s < 0$).

	s	u	k_e	g_s	Total
CSC-effect	14%	0	5%	15%	34%
RQ-effect	36%	8%	0	0	44%
RE-effect	0	0	0	22%	22%
Total	50%	8%	5%	37%	100%

An alternative formulation of the residual labor productivity hypothesis, would be to allow for a trend in the efficiency of capital equipment. KORV and others (e.g. Gordon 1990; Greenwood et al., 1997) have argued quite convincingly that advancements in investment-specific technology were responsible for the fall in the relative price of capital equipment (see Figure 3). KORV use (and extend) Gordon's (1990) quality adjusted price series for capital equipment in order to take this fact into account.

To explore the effects of this alternative formulation of the residual labor productivity hypothesis, the benchmark model is reestimated with a trend in the quality of

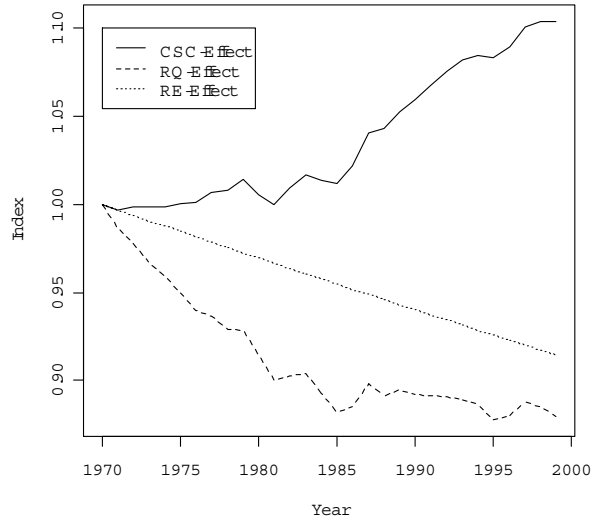


Figure 8: The Capital-Skill Complementarity Effect, The Relative Quantity Effect and the Relative Efficiency Effect ($g_s < 0$).

the stock of capital equipment added to the model, i.e. γ_s and γ_u are now both set to zero, while γ_e is now allowed to take on a nonzero value.³⁵ . As shown in Table 6, the parameter estimates are similar to those found in Tables 2 and 4. But now the unobservable trend is positive, which is more in line with Katz and Murphy (1992) and Bound and Johnson's (1992) trend in the demand for skilled workers. Furthermore, when there is capital-skill complementarity in production (as there is here), this formulation can be readily interpreted as skill-biased technological change.

The model fit is (for all intents and purposes) identical to the fit of the model with a trend in relative skilled efficiency shown previously in Figure 7. Results from the new decomposition experiment are reported in Table 7. The cumulative impact

³⁵For the sake of simplicity, the efficiency of capital equipment is model as a deterministic, linear trend with an initial value of one, i.e. $\Psi_{et} = 1 + \gamma_e t$.

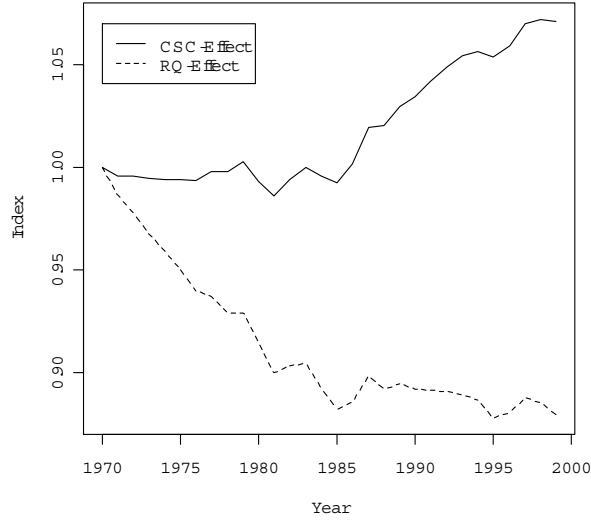


Figure 9: The Capital-Skill Complementarity Effect and the Relative Quantity Effect ($\gamma_e > 0$).

of the CSC-effect and the RQ-effect are shown in Figure 9.

Table 6: Parameter Estimates and Substitution Elasticities.

γ_{k_e}	σ	ρ	$S_{uk_e} = \frac{1}{1-\sigma}$	$S_{sk_e} = \frac{1}{1-\rho}$
0.008	0.3093	-0.9236	0	0
	(0.0096) ^a	(0.0429)		

a) Standard errors in parentheses.

Table 7: Decomposition of Changes in the Model Skill Premium ($\gamma_{k_e} > 0$).

	s	u	k_e	γ_{k_e}	Total
CSC-effect	19%	0	7%	18%	44%
RQ-effect	45%	11%	0	0	56%
Total	64%	11%	7%	18%	100%

In both of the models which allow for unobservable trends in the demand for

skilled labor, the importance of the capital-skill complementarity mechanism and the role of capital equipment is reduced (compare Tables 7 and 5 with Table 3). The main conclusion concerning wage inequality derived from the benchmark model, however, remains unchanged. Increased income inequality between high and low skilled workers is still demand driven and is due to the presence of capital-skill complementarity in production. This can be seen in Figures 8 and 9.

5 Conclusion

The goal of this study has been to increase our understanding of the underlying mechanisms responsible for the rise in income inequality in Sweden. The main conclusion of this study is that increased income inequality between high and low skilled workers is demand driven and is due to the presence of capital-skill complementarity in production. Increased investments in new, more efficient capital equipment, together with a slowdown in the growth rate of skilled labor, have raised the ratio of effective capital inputs per skilled worker, which, in turn, has increased the relative demand (and market return) for skilled labor through the capital-skill complementarity mechanism. A clear connection between macroeconomic developments and income inequality has been established which shows that investments in capital equipment and higher education affect the structure of relative wages in Sweden.

Previous research has shown that the capital-skill complementarity mechanism illustrated in this paper can also be used successfully to help us understand increasing wage dispersion (Caselli, 1999) and the behavior of the skill premium over the business cycle (Lindquist, 2004). Together, these and other studies, allow us to conclude that capital-skill complementarity is an important ingredient in a successful, competitive theory of relative wages and that such a theory can, in fact, help us to understand changes in the structure of relative wages.

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A Data Appendix

The skill premium used in this study was constructed using full-time equivalent, monthly salaries for male white-collar workers in Swedish mining, manufacturing and construction (SNI 2, 3 and 5). Skilled workers are those who have 3 or more years of post-secondary education. Unskilled workers are those who have at least three years of secondary education. These categories are roughly equivalent to US college and high school graduates, respectively. For the years 1970 to 1991, these figures were taken from Fredriksson (1997). For the years 1992 to 1999 the figures are taken from Statistics Sweden’s yearly publication, *Salaries for Employees in the Private Sector* (SCB9).

Values for capital equipment and capital structures can be found in the *Swedish National Accounts* published by Statistics Sweden (SCB4, SCB7, SCB8). Statistics Sweden changed their reporting methods for capital stocks in 1980. This change created a drop in the level between the series $k_{1970-1981}$ and $k_{1980-1999}$. To correct for this downward shift due to the change in methodology, we can use the two overlapping observations for 1980 and 1981 and calculate an adjustment weight. We can then correct for this level shift by multiplying the old series with the adjustment weight. This gives us $k_{e,1970-1999} = 0.7757 * k_{e,1970-1979} : 1 * k_{e,1980-1999}$ and $k_{s,1970-1999} = 0.9448 * k_{s,1967-1979} : 1 * k_{s,1980-1999}$. The splicing together of these two time series should not be problematic, since we are mainly interested in changes in the capital stock from year to year and not in the level of the capital stock.

The supply of skilled and unskilled workers for the whole economy are calculated from Statistic Sweden’s *Annual Labor Force Survey* (SCB6). Once again, skilled workers are those who have 3 or more years of post secondary education. Unskilled workers, however, are calculated by taking all workers, subtracting the number of skilled workers, and then adding both unemployed workers and latent job seekers. These figures are also taken from Statistic Sweden’s Annual Labor Force Survey (SCB6).

Prices indices for capital structures, capital equipment and consumption are taken from AMECO (a European Commission Database). The labor share of income is calculated using total labor costs (including taxes) and total value added (in factor prices) as reported in the *Swedish National Accounts* published by Statistics Sweden (SCB2, SCB3, SCB4).

B Econometric Appendix

There are several simulation-based estimation techniques suitable for estimating the parameters of the nonlinear state-space model comprised of Equations 9 - 11. Three such approaches are investigated in Ohanian, Violante, Krusell and Ríos-Rull (2000) (henceforth OVKR), which is a technical companion paper to KORV; numerical and stochastic integration, extended Kalman filter with indirect inference

correction, and simulated pseudo-maximum likelihood (SPML).³⁶ After conducting a number of Monte Carlo experiments, they compare the performance of these three alternative estimators given the particular model specification with trend stationary, latent state variables and a small sample size of 30 observations. They conclude that under these conditions the SPML method performs best in terms of precision and computational efficiency.

This method hinges on \mathbf{X}_t being strongly exogenous. Assuming that the stocks of capital equipment and capital structures are exogenous does not appear to be problematic. For even if current investments may be correlated with the shocks to labor productivity, the stock variables, themselves, move slowly over time and should not be correlated with contemporaneous shocks to labor productivity. There is, however, reason to believe that hours worked and employment are correlated with shocks to labor productivity. That is why the estimation is done using the number of skilled and unskilled workers in the economy. This is also why unemployed workers and latent job seekers are included in the measure for unskilled labor. The number of skilled and unskilled workers should more closely reflect the exogenous, long run supply of skilled and unskilled labor and are most likely not correlated with contemporaneous shocks to labor productivity.

The parameter vector ϕ includes 20 parameters. Given the small sample size at hand (30 observations) it seems appropriate to try and reduce the dimension of this vector. This can be done by calibrating several of the parameters and making some simplifying assumptions. First, the depreciation rates δ_s and δ_e are calibrated to equal 0.05 and 0.125, respectively. These values are the same as those used by Statistics Sweden in producing the estimates of the two capital stocks used in this paper. They are also identical to those used in KORV.

The income share of structures, α , is calculated from the data as the average of the yearly income share of structures under the assumption of equal returns, i.e. $r_e = r_s$

$$\alpha = \frac{1}{30} \sum_{t=1970}^{1999} \left[\frac{(r_s + \delta_s) k_{st}}{(r_s + \delta_s) k_{st} + (r_e + \delta_e) k_{et}} (1 - \theta_t) \right] = 0.1896, \quad (12)$$

where θ_t is the labor share of income at time t .

The standard error of the forecast error η_e is estimated as $(1 - \delta_e)$ times the standard error of the residuals of an $ARMA(1,2)$ model of q_{t+1}/q_t . The estimated equation has an $\overline{R}^2 = 0.65$ and $\hat{\sigma}_\varepsilon = 0.019$. So that η_e equals 0.017.

The dimensionality of ϕ can be reduced further by assuming that the covariance matrix, Ω , is equal to

$$\begin{bmatrix} \eta_{\overline{\omega}}^2 \\ \eta_{\overline{\omega}}^2 \\ \eta_{\overline{\omega}_e}^2 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}.$$

Under this set of assumptions, labor shocks have identical variance and zero covariance, i.e. $\eta_\omega = \eta_{\overline{\omega}_s} = \eta_{\overline{\omega}_u}$ and $\eta_{\overline{\omega}_{ij}} = 0$. The variance of shocks to labor efficiency,

³⁶For an overview of these types of simulation-based econometric methods see Gouriéroux and Monfort (1996).

η_{ϖ}^2 , is obtained as follows. First, the parameters η_{ϖ_s} and η_{ϖ_u} are estimated separately as the standard errors from an $ARMA(4, 4)$ process for skilled labor hours and an $ARMA(4, 3)$ process for unskilled labor hours.³⁷ Both equations have $\overline{R}^2 = 0.99$. Then, the standard errors of these two equations are made comparable by dividing each by the mean of the appropriate dependent variable. This results in $\eta_{\varpi_s} = 0.018$ and $\eta_{\varpi_u} = 0.019$. Thus, the assumption that $\eta_{\omega} = \eta_{\varpi_s} = \eta_{\varpi_u}$ appears to be a reasonable one and η_{ω} is set equal to 0.0185. The correlation coefficient of the residuals from these two forecasting equations is equal to 0.03. As such, the assumption of zero covariance between the shocks to labor efficiency appears plausible as well.

This set of assumptions also turns off the shocks to the efficiency of capital equipment. So that, φ_{et} becomes a deterministic time trend equal to $\varphi_{e0} + \gamma_e t$. This representation is the one most similar to the quality adjustments made to the data in the original KORV model.

Laroque and Salanié (1989) have shown that SPML estimators, such as the ones used in this paper are free from approximation bias and that the SPML estimator is consistent and asymptotically normal (see also Gouriéroux and Monfort, 1996). Their results, however, are asymptotic and are applicable to stationary environments only. Here, we have a nonstationary environment with trends in the latent variables and in the times series for factor prices and quantities. Furthermore, the sample used here is too small to rely upon asymptotic results.

These complications have been dealt with quite thoroughly in OVKR. In this paper, they use Monte Carlo techniques to analyze the small sample properties of the SPML estimator. They find that when the latent process is trend stationary, there is very little mean and median bias in the estimated parameters of the model even when the number of simulations performed is as low as 10. Simulating the model 50 times, they find that the mean bias is essentially zero for the key curvature parameters σ and ρ . The parameter estimates in this paper are based on 500 simulations of the model.

The benchmark model was estimated following the algorithm outlined in Appendix 2 of KORV and in their technical companion paper OVKR. The only difference is that they use a two-step method in order to correct for potential endogeneity, since they are using hours worked as their measure of labor inputs. As mentioned above, this problem is avoided here by using the number of skilled and unskilled workers (i.e. the potential labor supply) instead of actual hours worked.

The model which allows for growth in the relative efficiency of skilled labor inputs is estimated on a grid of potential values for $g_s \in \{-.10, -.09, -.08, \dots, 0.08, 0.09, 0.10\}$, where $g_s \equiv \gamma_s - \gamma_u$ and γ_u is normalized to zero. That is, the model is estimated in its entirety for each fixed value of g_s . The results from this set of estimations can then be compared and the parameter estimates associated with the estimated model for which the three structural equations (9-11) best match the data are the maximum likelihood estimates. A similar procedure is used when allowing for a trend in the efficiency of capital, γ_{ke} . Although this estimation procedure required a finer grid.

³⁷See Lindquist (2001) for more information concerning the data and estimations.