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EARLY-TRANSITION OUTPUT DECLINE REVISITED

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ABSTRACT: *In this paper we revisit the issue of aggregate output decline that took place in the early transition period. We propose an alternative explanation of output decline that is applicable to Central- and Eastern-European countries. In the first part of the paper we develop a simple dynamic general equilibrium model that builds on work by Gomulka and Lane (2001). In particular, we consider price liberalization, interpreted as elimination of distortionary taxation, as a trigger of the output decline. We show that price liberalization in interaction with heterogeneous adjustment costs and non-employment benefits lead to aggregate output decline and surge in wage inequality. While these patterns are consistent with actual dynamics in CEE countries, this model cannot generate output decline in all sectors. Instead sectors that were initially taxed even exhibit output growth. Thus, in the second part we consider an alternative general equilibrium model with only one production sector and two types of labor and distortion in a form of wage compression during the socialist era. The trigger for labor mobility and consequently output decline is wage liberalization. Assuming heterogeneity of workers in terms of adjustment costs and non-employment benefits can explain output decline in all industries.*

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INTRODUCTION

It is a well established stylized fact that all Central- and Eastern-European countries (CEE) and Commonwealth of Independent States (CIS) experienced a large aggregate output decline soon after they initiated the process of economic reforms. The decline resulted in an extensive theoretical and empirical research, which tried to understand its causes and economic mechanisms. Theoretical explanations of output decline can be divided into two strands of literature. According to the first one, the decline was caused by stabilization policies, which caused excessive inward shift of aggregate demand (e.g. Berg and Blanchard, 1994; Rosati, 1994). The second strand of the literature, recently receiving more attention, focuses on the factors underlying the inward shifts of aggregate supply. Calvo and Coricelli (1993) related the output decline to a reduction in available credit for financing production. Blanchard and Kremer (1997) built a model in which

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price liberalization triggers a process of bargaining between firms in vertical supply chains, which may, under incomplete contracts or asymmetric information, lead to an output decline.[3] Roland and Verdier (1999) propose a search model that relates price liberalization, interpreted as a freedom to contract, to output decline. The fall of output takes place because firms are willing to postpone their relational investment in a situation where the option of ongoing search is more valuable than immediate investment. Blanchard and Kremer (1997) recognized that their explanation was more relevant for CIS countries, which also applies to the model of Roland and Verdier (1999). For more liberal CEE countries that did not face such bargaining inefficiencies and information asymmetries, we still do not have a convincing explanation why price liberalization may have caused aggregate output decline.

In this paper we propose an alternative explanation of the output decline in CEE countries that partly builds on the work of Gomulka and Lane (2001). Starting with a simple two-period two-sector general equilibrium model, we first consider the effect of price liberalization, interpreted as elimination of distortionary taxation, on sectoral and aggregate dynamics of both output and employment. The elimination of price distortions increases the price of initially subsidized good and decreases the price of initially taxed good. This creates incentives for relocation of workers from the subsidized sector to taxed sector. However, workers are assumed to differ in terms of adjustment or mobility costs and non-employment benefits provided by the government and supplemented by income generated by working in informal economy. Specifically, both mobility costs and non-employment benefits increase with age of workers. These costs and benefits work as a sorting mechanism, creating incentives for younger workers to move to the sector with increasing prices and incentives to move to inactivity by older workers. The aggregate number of hours worked declines due to hours lost in mobility and hours lost due to inactivity of workers. While the output of sector with increasing price expands, this increase is smaller than a decline in the sector with declining price, causing aggregate output decline evaluated at initial relative prices. At the same time the adjustment costs create a wedge between the wages prevalent in the two sectors, thereby increasing the wage inequality.

This model has several attractive features that are not present in the model developed by Gomulka and Lane (2001). In particular, they assume prohibitive adjustment costs to labour mobility and predetermined real wages. These two assumptions imply that expanding sectors cannot employ additional workers and thus cannot increase output, while real wage rigidity causes a decline in sectors with increasing price. While their model can explain aggregate output decline, it is inconsistent with several stylized facts regarding the functioning of labour markets that our model takes into account. In particular, their model does not feature a large proportion of voluntary shifts of workers from employment to inactivity due to high non-employment benefits (see Boeri, 2000a; Boeri and Terrell,

3 Konings and Walsh (1999) used data for a sample of Ukrainian firms and showed that firms with more complex production structures indeed grew more slowly in terms of employment, which supports the theory developed by Blanchard and Kremer (1997).

2002; Vodopivec, Wörgötter and Raju, 2003)[4] and participation in an informal economy (Johnson, Kaufmann and Shleifer, 1997; Lacko, 2000), and completely ignores an increase in wage inequality during the period of output decline (Milanovic, 2002). The real wage rigidity assumed by Gomulka and Lane (2001) implies that labour outflows should be involuntary and inequality should not change. Our model also provides a more convincing explanation for the duration of output decline as we rely on non-employment benefits and income generated in informal economy, rather than on sustained wage rigidity in the economy with high unemployment and no government benefits. In our view, voluntary flows of workers to inactivity and persistence of the real wage rigidity had the same cause. The combined benefits put an effective lower bound on the real wages in declining sector and provided an attractive alternative to work in the official economy.

In spite of its attractive features, the two-sector model with price liberalization is not able to explain output decline that took place in virtually entire economy (see Roland, 2000). In the second part we show that wage liberalization, interpreted as elimination of cross-subsidization of less productive workers, could explain output decline in all industries as long as workers are different in human capital if we preserve similar heterogeneity of workers in terms of adjustment costs and non-employment benefits. However, given scarce microeconomic evidence, we cannot argue that the proposed mechanism dominates the effects of trade embargoes and aggregate demand shifts.

The remainder of the paper is organized in three sections. In the second section we present a model of price liberalization, the third section discusses the effects of wage liberalization. The last section concludes.

1 A MODEL OF PRICE LIBERALIZATION

In this section, we develop a simple theoretical model that allows us to analyze the effects of price liberalization on both sectoral and aggregate employment and output. Following the work of Gomulka and Lane (2001), we focus on a specific mechanism that works through changes in relative prices and thus leave aside bargaining inefficiencies and search frictions that could have arisen after price liberalization.

In our model price liberalization is considered as elimination of distortionary taxes on firms' revenues. In reality, however, socialist governments used a wide variety of measures that distorted both prices and allocations. On one hand, they interfered with decisions on employment, investments and new research activities, and on the other hand, they pursued desired allocations through direct setting of prices, wages and interest rates (Kornai, 1994). Since allocations, prices of production factors and prices of final goods were mostly inconsistent with the market determined ones, governments supported these allocations through extensive redistribution systems, which combined different types of

4 Even for Russia, where employment reductions were particularly modest, Earle and Sabirianova (2001) find that 75 percent of all separations were voluntary.

taxes and subsidies ranging from direct taxation to inflationary taxation.[5] Nevertheless, by focusing merely on one type of government intervention -- distortionary taxation -- and its elimination, no substantive insight is lost. In fact, in the framework with linear production technologies and exogenously given number of products that we consider below, distortionary tax system alone can generate any desired allocation of labour. Therefore, in what follows, we consider introduction and removal of only this type of government intervention.[6]

1.1 Setup

1.1.1 Firms

We assume that firms produce two distinct goods, x and y, according to the same Ricardian production function, which require one unit of labor to produce one unit of final good:

$$q_j = l_j, j = x, y, \tag{1}$$

where q_j and l_j denote sector j's output and employment, respectively. Since we are interested in a relatively short period of output decline that in CEE countries typically lasted two to three years, we assume away accumulation of physical capital and technological progress. In addition, firms face no entry and exit costs, which combined with constant returns to scale production function leaves market structure indeterminate. These assumptions greatly simplify the modeling framework, ensure tractability, and allow us to reduce the value maximization problem of firms into a standard profit maximization problem.

The profit of the representative firm producing good j is:

$$\pi_j = (1-\tau_j) p_j q_j - w_j l_j, \tag{2}$$

where p_j and w_j denote the price of good j and the wage rate paid for unit of labour in production of j, respectively. τ_j denotes the proportionate tax (or subsidy) rate levied on sales. Note that the choice of sales tax is not very restrictive as the same equilibrium allocations could be achieved by introducing sector specific taxation of gross wages. Namely, linear production functions imply that it is irrelevant what type of tax is used in order to distort allocation of labour between sectors, which can be observed from the first order conditions for profit maximization:

5 Note that disinflationary policies could have the same effect as price liberalization as subsidies through inflationary monetary policy had to be reduced.

6 Distortionary taxation and direct measures of resource allocation may give very different results in the context of new products and services. A ban on entry of private firms may effectively limit the extent of product variety, which could be achieved only by prohibitively high taxation on firm entry.

$$(1-\tau_j)p_j = w_j. \tag{3}$$

Since net wages were equal between sectors, differences in taxation of wages were reflected in labor costs and consequently in differences in prices.

1.1.2 Households

The economy is populated by a continuum of one worker/consumer households indexed on an interval between 0 and 1. Their utility function is defined over a consumption bundle of two goods and leisure time. The utility function for household i is:

$$u(x_i, y_i, v_i) = (x_i^{\frac{\sigma-1}{\sigma}} + y_i^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}} + \delta(H - v_i h), \quad 0 < \delta < 1. \tag{4}$$

The first part of (4) is a standard CES subutility function defined over quantities of goods x and y consumed with an elasticity of substitution, σ, that is assumed to exceed 1. The second part of (4) is a subutility function defined over leisure time, where H denotes the total time available per period and h denotes the statutory working time. For simplicity we shall assume that both parameters, H and h, assume value 1. δ is a weight that households give to leisure relative to consumption. In order to simplify the framework, we assume that working time regulation prevents free choice of working hours. Households can thus choose between working and not working, which is captured in an indicator variable v, which is equal to 1 in the former case and 0 in the latter case.

Household i maximizes the utility function in (4) subject to the following budget constraint:

$$p_x x_i + p_y y_i \le v_i \max\{w_{pi}, w_{ai}(1-\kappa i)\} + (1-v_i)\beta i, \quad \beta, \kappa \ge 0. \tag{5}$$

On the left-hand side is a standard expression for the cost of consumption bundle, whereas on the right-hand side is a non-standard expression for income earned per period, which also reflects the labor market choices that consumers face. Suppose first that consumer prefers activity to inactivity, i.e. v_i equals 1. In this case, she still faces the choice of sector of employment, which is made upon comparison of earned wages in the two sectors. w_{pi} and w_{ai} denote the wage rates earned per period in the prior and alternative sector of employment, respectively. For example, if worker stays employed in sector x, then w_{pi} equals to w_x. Alternatively, if worker, initially employed in sector x, moves to sector y, she earns a wage equal to $w_y(1-\kappa i)$. Here κi is the time lost in inter-sectoral mobility, such as search, re-training or commuting costs. κ is a parameter that determines the size of mobility costs, while i is an index of workers. Although in reality consumers may choose to use either working or leisure time for investment in mobility and that mobility may also entail other types of costs, such as monetary or psychical costs, the qualitative nature of results derived below does not hinge on assumed form of mobility costs. The key feature of assumed form of mobility costs is introduction of worker heterogeneity. We think of index i as a proxy for age, which implies that older workers face higher mobility costs. This assumption is readily justified. On one hand, over the work cycle, workers gradually lose general human capital, which is necessary for re-training. On the other hand, older workers may be less familiar with various search channels and are more likely to be tied to a specific location through ownership of housing. Moreover, older workers have shorter remaining life spans, which implies lower values of investments in mobility.[7]

Suppose next that worker prefers inactivity, i.e. v_i equals 0. In this case, the government provides non-employment benefits. We assume that the size of these benefits depends on parameter β and an index of worker. Thus, non-employment benefits introduce another type of heterogeneity of workers. This assumption can be justified by actual institutional arrangements prevalent in Central and Eastern European countries (see Boeri and Terrell, 2002; Vodopivec et al., 2005), which typically entitled older workers to more generous non-employment benefits. Namely, the rules that determined entitlements typically related the amount and length of both unemployment benefits and severance payments to age. Moreover, an early retirement option was typically given only to workers older than some statutory minimum age.

The solution to the utility-maximization problem given by the objective function in (4) and the budget constraint in (5) can be found in two steps. In the first step, we determine the demand functions for both goods, which are then used in the second step – calculation of indirect utility functions related to different labor market choices. The demand functions are obtained from the first order conditions for utility maximization. These have a well-known form for CES utility function:

$$x_i^d(I_i, p_x, p_y) = \frac{p_x^{-\sigma}}{p_x^{1-\sigma} + p_y^{1-\sigma}} I_i,$$

$$y_i^d(I_i, p_x, p_y) = \frac{p_y^{-\sigma}}{p_x^{1-\sigma} + p_y^{1-\sigma}} I_i,$$

where demand functions of consumer i, x_i^d and y_i^d, depend on the relative price of goods and combined income and non-employment benefits (I_i).[8] The expression for income depends on the labour market choices that workers make. In general, there are five different choices that workers can make and thus five different types of workers. However, since changes in the relative wage are symmetric, it is sufficient to consider only one direction of wage change. In particular, we shall assume that price liberalization terminates preferential treatment of sector x and consequently to reduction of wage in

7 We recognize that proper treatment of time to invest consideration requires introduction of vintage human capital and overlapping generations structure. This would, however, greatly complicate the model without changing the substantive results of much simpler model that we propose.

8 Note that assumed inability of workers to transfer resources between periods implies equality of individual income and expenditure.

sector x. Given this assumption, we are left with four different groups of workers. In the first group are workers that stay in sector x and earn wage rate and income w_x. In the second group are workers that move from sector x to sector y and earn income $w_y(1-\kappa i)$. In the third group are workers that move from sector x to inactivity and earn βi and in the last group are workers that stay in sector y and earn w_y.

As already noted, each labour market choice corresponds to a specific form of demand functions and thus also different indirect utility functions. Labour-market choice is made upon ranking the values of indirect utility functions. Given assumed pre-transition preferential tax treatment of sector x, after price liberalization workers employed in sector y will not have incentive to move either to sector x or to inactivity.[9] On the other hand, workers in sector x must compare the indirect utilities of three labour-market choices. The assumptions of increasing mobility costs and non-employment benefits with age imply that in equilibrium only the youngest workers move to sector y, the middle-aged workers stay in sector x and the oldest workers become inactive. The comparison of indirect utility functions gives the following conditions for the youngest workers:

$$w_y(1-\kappa i) \geq w_x, \text{ for } i \leq i_{xy}, \tag{6}$$

where i_{xy} denotes the index of worker that is indifferent between staying in sector x and moving to sector y. On the other end of age distribution, only those workers employed in sector x move to inactivity for which holds that nonemployment benefit exceeds the wage earned in sector reduced by the value of lost leisure time. Formally, this condition can be stated as

$$\beta i \geq w_x - \delta, \text{ for } i \geq i_{xu}, \tag{7}$$

where i_{xu} denotes the index of worker that is indifferent between staying in sector x and becoming inactive.

The aggregate demand functions are calculated as sums of individual demand functions. Hence, these are:

$$X^d = \frac{p_x^{-\sigma}}{p_x^{1-\sigma} + p_y^{1-\sigma}} \int_0^1 I_i di,$$

$$Y^d = \frac{p_y^{-\sigma}}{p_x^{1-\sigma} + p_y^{1-\sigma}} \int_0^1 I_i di, \tag{8}$$

where the integral runs over all consumers.

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9 We shall assume that the highest non-employment benefits cannot exceed the income earned in sector y. This assumption is necessary in order to prevent outflows of workers from the sector y as well.

1.1.3 Government

The government collects revenues by imposing sales tax, which is spent either on subsidies of firms' revenues or non-employment benefits to inactive workers. We assume that the government complies with the balanced budget constraint in each period:

$$\tau_{xt} p_{xt} X_t + \tau_{yt} p_{yt} Y_t = \int_{\Omega} \beta_t i di, \tag{9}$$

where Ω denotes the set of inactive workers. We assume that in the pre-transition period government subsidizes revenues of sector x and taxes revenues of sector y. In the transition period, government liberalizes prices by eliminating distortionary tax rates and applies one tax rate in both sectors.

1.2 Pre-transition equilibrium

Equilibrium in any period cannot be determined unless we make an assumption on the prior sectoral allocation of labour. Namely, the incentives for mobility between sectors and to inactivity depend on the interplay between prior labour allocation and current period tax policy. In order to focus on the transition period dynamics, we assume that prior labour allocation corresponds to current tax policy in a way that workers have no incentives to move from sector of initial employment. In other words, we assume a stationary pre-transition equilibrium. Furthermore, we assume that prevalent wage exceeds non-employment benefits for all workers and that no one prefers inactivity to work. This assumption normalizes the pre-transition inactivity to zero.

We are now ready to characterize the pre-transition equilibrium. Since this is the first period in our model, all the variables for this period have sub-index 1. We select labour as a numeraire and set the wage rate to 1. Note again that we assume that socialist government preferred goods produced in sector x and subsidized its revenues for which it raised resources by taxing the revenues of y. These assumptions and the first order condition for the profit maximization give:

$$p_{j1} = \frac{1}{(1-\tau_{j1})}, j \in \{x, y\}, \tag{10}$$

which implies that the relative price of good y in terms of good x, p_{y1} / p_{x1}, exceeds 1. Plugging the pricing equation (10) in the aggregate demand function (8), we get the relationship between the tax rates and output levels. The assumed form of production functions (1) also implies equality between output and employment levels:

$$X_1 = \frac{(1-\tau_{x1})^{\sigma}}{(1-\tau_{x1})^{\sigma-1} + (1-\tau_{y1})^{\sigma-1}} = L_{x1}, \tag{11}$$

$$Y_1 = \frac{(1-\tau_{y1})^{\sigma}}{(1-\tau_{x1})^{\sigma-1} + (1-\tau_{y1})^{\sigma-1}} = L_{y1}. \tag{12}$$

Note that employment and output increase with increases in respective tax rates. In particular, as government imposes a positive tax rate on revenues generated in sector y and thus a negative tax rate on revenues generated in sector x, the output and employment levels in sector x exceed those of sector y.

In order to complete the characterization of equilibrium, we need to establish the relationship between the tax rates. This relationship is obtained from the balanced budget constraint and the labor market clearing condition:

$$L_{x1} + L_{y1} = 1 \tag{13}$$

Since no worker opts for inactivity, the balanced budget constraint simpifies to

$$\tau_{x1} p_{x1} X_1 + \tau_{y1} p_{y1} Y_1 = 0.$$

Using the pricing relations (10), the equilibrium output, the labor allocations given in (11) and (12) and the labor market clearing condition (13), we get the following relationship between the tax rates in the two sectors:

$$\tau_{x1}(1-\tau_{x1})^{\sigma-1} = -\tau_{y1}(1-\tau_{y1})^{\sigma-1}. \tag{14}$$

This relationship depends on the value of elasticity of substitution. For Cobb-Douglas utility with σ equal to 1, there is a linear relationship between the tax rates. Specifically, an increase in τ_{y1} by one percentage point implies a decrease in τ_{x1} by one percentage point. For values of σ exceeding 1, this relationship is non-linear. For values of σ below 2.5, this relationship is monotonically decreasing for a wide range of τ_{y1}. In what follows, we shall consider only values of σ for which higher τ_{y1} corresponds to lower τ_{x1}. It is also important to note that higher values of σ correspond to higher τ_{y1} for given τ_{x1}, which is a consequence of greater responsiveness of firms' revenues to changes in tax rates.

1.3 Transition equilibrium

We now turn to determination of equilibrium in transition period. All the variables for this period have sub-index 2. We start by assuming complete price liberalization, which government achieves by imposing equal tax rates for all sectors. As a consequence, the prices that firms set must change as well, which is evident from the modified price-setting equation:

$$p_{j2} = \frac{w_{j2}}{(1-\tau_2)}, j \in \{x, y\}, \tag{15}$$

Namely, the price of good x must increase, whereas the price of good y must decrease. These price shifts change the structure of aggregate demand in favour of good y. If workers faced no obstacles to mobility, they would move from sector x to sector y and the wage rates and prices in two sectors would equalize as well. However, we assumed that workers face mobility costs that increase with age (index) of workers. Hence, the wage rates and prices can no longer be equal in two sectors. The relative price of good x, p_{x2} / p_{y2} is thus equal to the relative wage rate in sector x, w_{x2} / w_{y2}.

The relative wage rate is determined by an arbitrage condition given in (6). Continuously increasing mobility costs ensure that there exists a worker with an index i_{xy2}, who is indifferent between staying in sector x and moving to sector y. For this worker the wage rate earned in sector y multiplied by the share of remaining time after mobility between sectors must be equal to the wage rate (and wage) earned in sector x:

$$w_{y2}(1-\kappa i_{xy2}) = w_{x2}. \tag{16}$$

This equation segregates workers previously employed in sector x. Only those with index (age) below i_{xy2} move to sector y, while older workers either stay in this sector or move to inactivity. Equation 15 implies that these differences in wages are also reflected in differences in prices across sectors.

The second arbitrage condition stems from decisions of workers initially employed in sector x with index that exceeds i_{xy2}. These workers face sufficiently high mobility costs to have no incentive to move between sectors. From inequality (7) we know that only workers above certain age decide to become inactive. That is, continuously increasing non-employment benefits imply that for sufficiently high β_2, there exists a worker who is indifferent between inactivity and work in sector x. We denote the index of this worker by $i_{x1} - i_{xu2}$. The arbitrage condition that relates non-employment benefits parameter and the wage rate in sector x is:

$$\beta_2(i_{x1} - i_{xu2}) = w_{x2} - \delta. \tag{17}$$

In order to calculate the equilibrium prices and allocations, we need to determine the indices of marginal workers, i_{xy2} and i_{xu2}. For this purpose, we need to use labour and final goods market clearing conditions. The goods market clearing conditions equate the aggregate demand and supply functions. However, due to Walras law, we only use one of these conditions. Namely, using the expressions for aggregate demand (8) and aggregate supply of labour, the good x market clearing condition is:

$$X_2^d = \frac{p_{x2}^{-\sigma}}{p_{x2}^{1-\sigma} + p_{y2}^{1-\sigma}} I_2 = L_{x2} = X_2^s. \tag{18}$$

Here I_2 is the aggregate income that is a sum of incomes for four groups of workers: i) the young who move from sector x to sector y and earn wage $w_y(1-\kappa i)$, ii) the middle-aged who stay in sector x and earn wage w_{x2}, iii) the old who move from sector x to inactivity and receive nonemployment benefits $\beta_2 i$ and iv) all workers that are employed in sector y. Formally, the aggregate income is:

$$\begin{aligned} I_2 &= w_{y2}\int_0^{i_{xy2}}(1-\kappa i)di + w_{x2}\int_{i_{xy2}}^{i_{x1}-i_{xu2}}di + \beta_2\int_{i_{x1}-i_{xu2}}^{i_{x1}} idi + w_{y2}\int_{L_{x1}}^{1} di \\ &= w_{x2}(i_{x1} - i_{xu2} - i_{xy2}) + w_{y2}(1 - i_{x1} + i_{xy2} - \frac{\kappa}{2} i_{xy2}^2)) + \beta_2 i_{xu2}(2i_{x1} - i_{xu2}). \end{aligned} \tag{19}$$

Here we have used the same ordering of workers as above. Note also that normalization of aggregate labor time to 1 implies that indices, or differences between indices, represent labor shares. For example, i_{x1} is an index of the last worker employed in sector x in the first period and the share of labor engaged in this sector in the pre-transition period. Similarly, i_{xy2} is a share of young movers from sector x to sector y, i_{xu2} is the share of older workers that move to inactivity and $\kappa / 2\, i_{xy2}^2$ is a share of labor lost due to inter-sectoral mobility. Combining pricing relations (15), (16) and (17) with goods (18) and labour market-clearing conditions:

$$i_{x2} = i_{x1} - i_{xu2} - i_{xy2}, \tag{20}$$

allows us to eliminate the wage rates, the prices and β_2 from the goods market clearing condition. We obtain the first of the two equations with two unknowns, i_{xy2} and i_{xu2}, that determine the transition equilibrium:

$$\frac{(1-\tau_2)}{1+(1-\kappa i_{xy2})^{\sigma-1}}\left(1+\frac{(1-i_{x1})+i_{xy2}(1-\frac{\kappa}{2}i_{xy2})}{(1-\kappa i_{xy2})(i_{x1}-i_{xu2}-i_{xy2})}+\frac{(1-\delta)i_{xu2}(2i_{x1}-i_{xu2})}{(i_{x1}-i_{xu2})(i_{x1}-i_{xu2}-i_{xy2})}\right)=1. \tag{21}$$

The second equation that determines the equilibrium is obtained by combining the balanced government budget constraint

$$\tau_2(p_{x2}X_2 + p_{y2}Y_2) = \beta_2 \int_{i_{x1}-i_{xu2}}^{i_{x1}} idi,$$

with pricing relations (15), (16) and (17), production function (1) and labor market clearing condition (20), to:

$$\frac{\tau_2}{1-\tau_2}\left((i_{x1} - i_{xu2} - i_{xy2}) + \frac{(1-i_{x1}) + i_{xy2}(1-\frac{\kappa}{2}i_{xy2})}{(1-\kappa i_{xy2})} \right) = \frac{(1-\delta)i_{xu2}(2i_{x1} - i_{xu2})}{(i_{x1} - i_{xu2})}. \quad (22)$$

The system of equations (21) and (22) determines the shares of workers in sector x that move either between sectors, i_{xy2}, or to inactivity, i_{xu2}. These, in turn, determine the equilibrium output levels, the prices and the wage rates. Since the solution to this system can not be expressed analytically, we examine the role of various parameters of the model in a simple simulation exercise. However, our highly stylized model is not suitable for calibration to real transition economies, which makes the choice of parameters arbitrary, serving only illustrative purpose.

1.3.1 Simulation exercise

In order to calculate the equilibrium allocations and prices, we need to choose the values of parameters. We start with parameters that determine the pre-transition allocation of labour, which also affects the transition equilibrium. From equations (10), (11), (12) and (14) follows that only two parameters, elasticity of substitution and sales tax rate in one of the sectors, determine this equilibrium. In the baseline scenario, for which we summarize parameter values in Table 1, we assume elasticity of substitution equal to 1 and a 15 percent subsidy rate on revenues generated in sector x in the pre-transition period. This subsidy rate corresponds to a 15 percent tax rate on revenues generated in sector y. For these parameter values and the wage rate set to 1, we have employment and output levels in sectors x and y, summarized in the first column of Table 2, equal to 0.575 and 0.425, respectively. The prices of goods x and y that support these allocations are 0.870 and 1.177, respectively. In other words, preferential subsidy given to firms in sector x allows them to set lower price and increase employment and output by 15 percent at the expense of employment and output in sector y.

Now that we have determined the pre-transition labour allocation, we need to choose the remaining values of parameters that affect the transition equilibrium. In particular, we need to specify the weight of leisure in the utility function, the common tax rate on firms' revenues, and the mobility cost parameter, κ. In the baseline scenario, we set δ to 0.35, which implies that additional unit of leisure increases utility by the same amount as an increase of consumption of both goods from, say, 0.50 to 0.85 units. κ is set to 3, which on one hand implies zero mobility cost for the youngest worker in sector x, while the oldest worker faces prohibitive mobility cost equal to 2.1 units of leisure time. The common sales tax rate in transition is set to

0.065, which in equilibrium implies β_2 equal to 1.343. This gives a range of non-employment benefits between 64.9 percent of the wage rate in sector x for the youngest and 77.2 percent for the oldest mover to inactivity.[10]

The transition period prices and allocations for this scenario are summarized in the lower part of the first column of Table 2. In comparison to the pre-transition levels, the output and employment levels in sector x decline from 0.575 to 0.466, a 18.96 percent decline, whereas the output and employment in sector y increase from 0.425 to 0.441, a 3.76 percent increase. As the decline of employment in sector x exceeds the increase of employment in sector y, there is a 10.2 percent aggregate employment decline. A large part of output decline in sector x is related to outflow of workers to inactivity (i_{xu2} is 0.091), although there is also a small part related to inter-sectoral mobility of workers (i_{xy2} is 0.017). The share of labour lost due to high mobility costs is relatively low ($\kappa / 2\, i_{xy2}^2$ is 0.0004). The prices that support these allocations changed as well. An increase in production of good y is consistent with consumer optimization only if the relative price of this good decreases. Moreover, while in the pre-transition period workers in two sectors earned the same wage rate, in transition period the wage rate in sector y exceeds the wage rate in sector x by 5.52 percent. In other words, wage inequality increases due to mobility costs that determine the sectoral wage gap. The change in aggregate output or real GDP depends on the choice of appropriate weights for the two goods. Following the standard methodology of statistical offices, we use the prices applicable in the pre-transition period. Due to relative scarcity of good y in the pre-transition period, the relative price of good y in this period is higher than in the transition period. Thus, while output of good y increases in transition period and output of good x decreases, the real GDP decline is smaller than the aggregate labor decline. For the baseline parameter values, the aggregate output decline amounted to 7.45 percent, which is 1.70 percentage points less than the aggregate employment decline.

Table 1: *Baseline parameter values*

Parameter	Description	Value
σ	Elasticity of substitution	1.000
w_1	Pre-transition nominal wage rate	1.000
w_{x2}	Transition nominal wage rate in sector x	1.000
δ	Weight of leisure in utility function	0.350
τ_{x1}	Pre-transition subsidy rate on revenue in sector x	-0.150
τ_{y1}	Pre-transition tax rate on revenue in sector y	0.150
τ_2	Transition tax rate on firms revenues	0.065
κ	Adjustment cost parameter	3.000

10 Note that we consider only tax rates that are to the left of the maximum of the Laffer curve. Over that range of parameter values, higher tax rate corresponds to higher non-employment benefits.

Table 2: *The equilibrium allocations and prices for the baseline parameter values and alternative assumptions*

	Baseline parameter values	**Deviations from the baseline scenario**				
		$\tau_{y1} = 0.20$	$\sigma = 1.50$	$\kappa = 5.00$	$\tau_2 = 0.10$	$\delta = 0.45$
Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
$Q_{x1} = L_{x1}$	0.575	0.600	0.623	0.575	0.575	0.575
$Q_{y1} = L_{y1}$	0.425	0.400	0.377	0.425	0.425	0.425
p_{x1}	0.870	0.833	0.870	0.870	0.870	0.870
p_{y1}	1.177	1.250	1.216	1.177	1.177	1.177
GDP_1	1.000	1.000	1.000	1.000	1.000	1.000
$Q_{x2} = L_{x2}$	0.466	0.475	0.492	0.470	0.438	0.457
$Q_{y2} = L_{y2}$	0.442	0.430	0.412	0.438	0.431	0.438
i_{xy2}	0.017	0.032	0.037	0.013	0.006	0.014
i_{xu2}	0.091	0.093	0.094	0.092	0.131	0.104
$L_2 = L_{x2} + L_{y2}$	0.908	0.906	0.904	0.908	0.892	0.895
p_{x2}	1.069	1.087	1.069	1.069	1.111	1.069
p_{y2}	1.129	1.201	1.204	1.147	1.131	1.115
GDP_2^{CP}	0.925	0.934	0.929	0.924	0.888	0.913
w_{y2}	1.055	1.105	1.125	1.072	1.017	1.043
$\kappa / 2\, i_{xy2}^2$	$4 \cdot 10^{-4}$	$15 \cdot 10^{-4}$	$20 \cdot 10^{-4}$	$4 \cdot 10^{-4}$	$0.5 \cdot 10^{-4}$	$3 \cdot 10^{-4}$
β_2	1.343	1.282	1.228	1.345	1.463	1.167

Note: Columns (2)-(6) differ from the baseline scenario only in the value of parameter in the head of the table.

Next, we examine the effects of parameter variation on equilibrium outcomes. We compare equilibria by varying one parameter, while keeping all remaining parameter values in line with the baseline scenario. First, we consider greater initial miss-allocation. In our model, this is achieved by an increase in the tax rate on revenues of sector y from 15 to 20 percent. The equilibria that correspond to higher value of τ_{y1} are summarized in the second column of Table 2. Higher τ_{y1} is reflected in greater employment and output levels in sector x and lower employment and output levels in sector y in the pre-transition period. As a consequence, removal of distortions creates greater incentives for mobility of workers from sector x to both sector y and inactivity. Therefore, we can observe greater employment and output decline in sector x, and greater employment and output surge in sector y in the transition period. Nevertheless, the size of the aggregate employment decline is greater. Since greater distortions imply that more workers bear mobility costs, there is also greater wage inequality. At the same time we observe lower endogenously determined β_2. This result suggests that countries with worse miss-allocation of labour could not afford to pay as generous non-employment benefits as countries with smaller distortions. The most important, but also controversial, prediction of the model is related to the change in real GDP in response to an increase in τ_{y1}. The model predicts that this relationship is negative, which counters empirical observation that countries with worse initial conditions experienced greater output decline. It is important to note that we obtained our theoretical result by applying the pre-transition prices, which is theoretically equivalent to applying GDP deflators on nominal GDP growth rates. However, one should bear in mind well-documented measurement errors pertaining to calculation of change in real GDP. Both under-reporting of activity in small and growing firms and over-estimated measures of inflation due to coverage of primarily large firms with above average price increases could lead to overestimated output decline (Bartholdy, 1997).[11] Moreover, the extent of real GDP growth could be substantially reduced in a proper multi-period setting in which adjustment of workers could not take place within an interval of one time period. Nevertheless, the prediction that countries with greater distortions could experience smaller output decline raises concern and suggests that the proposed model can only complement the existing explanations of output decline, rather than replace them. This conviction is reinforced when higher values of elasticity of substitution are considered. In the fourth column of Table 2 we show the pre-transition and transition equilibria for σ equal to 1.5 and conclude that higher elasticity of substitution leads to greater dispersion of prices and miss-allocation of labour in the pre-transition period and greater decline of aggregate employment, while real GDP decline is in fact lower.

Next, we consider variation of parameter that reflects mobility cost, κ, which implies a proportionate change of mobility costs for all workers in sector x. The equilibria that correspond to this type of deviation from the baseline scenario are summarized in the fourth column of Table 2. An increase in κ to 5, does not affect the pre-transition equilibrium. However, since all workers in sector x face higher mobility costs, the transition equilibrium exhibits a smaller share of workers in sector x that move to sector y and a greater share of workers that become inactive. The share of workers that stay in sector x is thus higher, while the share of workers employed in sector y is lower. The net effect of higher adjustment costs is lower aggregate employment and lower real GDP. Moreover, higher κ also implies greater difference between hourly wage rates and thus greater dispersion of income between households. It is also important to note on the relationship between κ and employment lost due to mobility costs, $\kappa / 2\, i_{xy2}^2$. While higher κ reduces i_{xy2}, the direction of change of aggregate mobility costs depends on response of i_{xy2} to κ. In general, the relationship between κ and aggregate mobility

11 Inability of the model to replicate the observed empirical relationship between the initial distortions and the extent of output decline is related to the assumption that the socialist governments achieved the desired allocations of resources only by distortionary taxation. This assumption, however, does not include the possibility that government used a ban on entry of private firms that could increase the variety of products. In that situation, sectoral output would not respond to a change in relative prices, but rather to liberalization of entry of firms. More importantly, changes of prices of goods could only be measured for existing firms. Therefore, application of GDP deflators, based on prices of continuing firms, to nominal GDP changes could yield greater output decline especially in those countries with worse initial distortions.

costs is hump-shaped. For low values of κ its increases lead to higher aggregate mobility costs and vice versa. In extreme case, where κ is prohibitive for all workers in sector x and there are insufficient benefits to participation in hidden economy, no worker would decide to move from sector x and employment (and output) in all sectors would remain unchanged. In summary, for moderate values of κ, the model predicts that countries with higher inter-sectoral mobility costs should exhibit greater output decline, greater income inequality and higher share of inactive workers.

The third experiment is variation of the common tax rate on the transition equilibrium. As higher tax rate corresponds to higher parameter for non-employment benefits, we interpret this experiment as a variation of generosity of non-employment benefits system.[12] The results for higher τ_2, equal to 0.10, which corresponds to β_2 equal to 1.463, are summarized in the fifth column of Table 2. Higher non-employment benefits make inactivity preferred choice for more workers in sector x. This decreases the share of employed workers in sector x, which implies that good x is relatively more scarce and its relative price is higher. As a result of, the wage gap between sectors and wage inequality are smaller, which reduces the incentives for inter-sectoral mobility and employment in sector y. The aggregate employment and the real GDP that correspond to higher non-employment benefits are both lower. Thus, in conclusion, this model predicts that countries that offered more generous non-employment benefits to inactive workers should exhibit greater output declines and lower wage inequality.

Lastly, we consider the effects of variation of relative value of leisure, captured by parameter δ. This parameter allows an alternative interpretation, namely, a measure of relative productivity in formal as opposed to informal economy. As countries with higher relative productivity in formal economy are typically more developed with higher GDP, the relative value of leisure may be lower. In other words, variation of δ may capture differences in the initial level of GDP per capita. In Table 2, we report the transition equilibrium that corresponds to the value of δ equal to 0.45, which is higher than in the baseline scenario. An increase of relative value of leisure has similar effect on labour flows as an increase of transition-period tax rate. Namely, the share of workers that stay employed in the two sectors decreases, which results in higher aggregate employment and output decline. Higher outflow of workers from sector x to inactivity also implies lower wage inequality. The only difference is that non-employment benefits parameter decreases, which is a consequence of lower taxes collected due to outflow of workers to inactivity. In conclusion, countries with lower income per capita should exhibit greater output decline as inactivity may be a more attractive option for greater share of workers in declining sectors.

12 The standard Laffer curve features a hump-shaped relationship between the tax rate and the total tax revenue. The setup of this model features this relationship. However, as an increase in the tax rate increases the outflow of workers from sector x, the relative price of this good increases and thus eliminates the incentive for outflow to more workers and further output decline. As a consequence, the relationship between the tax rate and the mass of taxes is only positive in this setup. The case where this relationship could be negative is rulled out as it would feature a decline in output also in sector y.

1.4 Trade embargo

Above we show that the model of price liberalization predicts that countries with greater initial distortions, ceteris paribus, should exhibit smaller output decline due to offsetting effect of sectoral changes in production and initial relative prices. In fact, under extremely large distortions, we could observe even real output surge. The second prediction that runs against the evidence is that the real GDP decline is smaller than the aggregate labour decline. In reality, we have observed that output decline is typically greater than that of aggregate employment, which suggests that other mechanisms may have played more important role.

One important peace of evidence is that countries with greater export shares to CMEA countries exhibited greater output decline. Djankov (1998) pointed out that FSU countries imposed import tariffs or even complete bans of imports. This trigger is easily analysed within our setup as an introduction (or an increase) of import tariffs also works through changes in relative prices. The appeal of this trigger of relative price changes is movement of prices and quantities in the same direction rather than in the opposite when relative prices change due to distortionary taxation, and consequently greater aggregate output decline.[13]

In order to illustrate this point, we assume a small open economy with exogenously given relative prices. Let us denote the relative price in CMEA as $(p_x/p_y)^C$ and assume that its value exceeds 1. Exogenously given relative price allows us to determine the pattern of pre-transition specialization. Keeping the same form of production function as above, the relative productivity of two sectors is equal, which combined with common wage rate across sectors implies that the relative price in closed economy is equal to 1. Thus, given higher relative price of good x in CMEA, the country completely specializes in its production.[14] That is, output and employment in sectors x and y are 1 and 0, respectively. The pre-transition period levels of exports and imports are determined by plugging the aggregate demand functions given in (8) in the balanced international trade constraint:

$$X^e = X^s - X^d = 1 - \frac{p_x^{-\sigma}}{p_x^{1-\sigma} + p_y^{1-\sigma}} I_i =$$

$$= 1 - \frac{p_x^{-\sigma}}{p_x^{1-\sigma} + p_y^{1-\sigma}} p_x = 1 - \frac{1}{1 + (\frac{p_y}{p_x})^{1-\sigma}}.$$

13 Autor, Dorn and Hanson (2016) analyze show that entry of China in WTO in 2001 lead to important changes in employment of US workers and output. These effects are in our model analogous to trade embargo, but with the opposite direction of adjustment of workers.

14 While complete specialization is extreme, this is a consequence of preserving the same structure of economy as in the model of price liberalization. Modelling more complicated trade structure would necessarily yield more complicated expressions without changing the qualitative nature of results.

e fact that $I = w = p_x$. Thus, higher relative price of good x implies higher exports share. Similarly, the pre-transition imports is increasing in relative price:

$$Y^m = Y^s - Y^d = 0 - \frac{p_y^{-\sigma} p_x}{p_x^{1-\sigma} + p_y^{1-\sigma}}$$

Let us now consider the effect of trade embargo that takes place in the transition period. The equilibrium is determined in the same way as above. The only peculiarity is the extreme initial condition, which features complete specialization, and implies the same change in sectoral employment and outptu, irrespective of the change in initial relative prices. An important difference is, however, the prediction that the change in real GDP is increasing with relative price of x. For higher relative price of x greater weight is given to the decline in production of x and lower weight is given to the production of good y, which confirms our point. This result suggests that trade embargos (or increases in tariffs) likely had important effects on output decline in the FSU countries and possibly in CEE countries.

2 A MODEL OF WAGE LIBERALIZATION

In the previous section, we analysed output and employment dynamics in a model that featured simultaneous price and wage liberalization. The price liberalization acted as a trigger for the relative price change, while wage liberalization was necessary to enable also changes in wages, which induced inter-sectoral labour reallocation. In this section we show that wage liberalization alone could have generated labour mobility that resulted in simultaneous output decline. Moreover, unlike in the model with price liberalization, this model predicts that output decline takes place in all firms simultaneously. In order to show this, we modify the model developed before in two directions. First, we assume only one production sector with firms producing one homogeneous good. Second, we assume that workers differ in terms of skills. The former assumption simplifies the model, while the latter introduces heterogeneity of labour in terms of acquired human capital. As before, we shall assume that socialist government uses distortionary taxation that affects the skill composition in the labour force. This assumption is clearly not realistic as socialist governments typically achieved wage compression by direct wage determination. However, it is a convenient assumption in order to preserve a common modelling framework in the two periods.[15] The presentation of the setup of the model and key results follows the same structure as above.

15 In order to achieve no unemployment among low-skill workers, direct wage determination needs a complementary intervention -- direct employment determination. If governments did not intervene in such way, low-skill workers would be unemployed. This phenomenon was often referred to as latent unemployment.

2.1 Setup

3.1.1 Producers

We assume that firms produce the final good according to the standard Cobb-Douglas production function with two production factors:

$$q = l_s^{\psi} l_u^{1-\psi}. \tag{23}$$

Here q, l_s and l_u denote output, skilled and unskilled labour, respectively. As above, we shall omit time indices in the presentation of the setup. ψ and $1-\psi$ are elasticities of output with respect to skilled and unskilled workers. Again, we assume costless entry and exit of firms, which combined with constant returns to scale production function leaves market structure indeterminate. The profit of the representative firm is:

$$\pi = pq - w_s l_s - w_u l_u, \tag{24}$$

where w_s and w_u denote the gross wage rates for skilled and unskilled workers, respectively. We choose the composite good to be a numeraire and set its price, p, to one. The first-order conditions for profit maximization are:

$$\psi l_s^{\psi-1} l_u^{1-\psi} = w_s, \tag{25}$$

$$(1-\psi) l_s^{\psi} l_u^{-\psi} = w_u. \tag{26}$$

From these conditions, we obtain firm-level demand functions, which have, due to linear homogenity of production function, the same form as aggregate production functions:

$$L_s^d = \psi \frac{Q}{w_s}, \tag{27}$$

$$L_u^d = (1-\psi)\frac{Q}{w_u}. \tag{28}$$

Here L_s^d and L_u^d denote aggregate labor demand functions for high- and low-skilled workers, respectively, and Q denotes the aggregate output. These expressions imply that labor demand increases with increases in aggregate output and weight in utility function and decreases with increases in gross wage rates.

2.1.2 Households

The economy is populated by a continuum of households, whose index (age) is evenly distributed on an interval between 0 and 1. The utility maximization problem for these households is similar to that given in (4) and (5). However, since we no longer have two types of goods, the utility function simplifies to:

$$u(q_i, v_i) = q_i + \delta(H - v_i), \delta > 0, \tag{29}$$

where q_i denotes a quantity of the composite good consumed by worker i. The labour market choices that individuals make are reflected in budget constraints with one important difference. In the two-sector model, workers made choice between sectors of employment and inactivity, whereas here only low-skilled workers face a choice on investment in skills and inactivity as they represent a group that experiences a negative income shock after wage liberalization. In particular, since elimination of distortionary tax on wages increases the relative wage of high-skill workers, low-skill workers decide between increasing their human capital, not investing in human capital, but staying employed, and becoming inactive, while high-skill workers face no trade-off and just consume their income. The budget constraint that reflects these choices of low-skill workers is:

$$q_i \leq v_i \max\{w_u(1-\tau_u), w_s(1-\tau_s)(1-\kappa i)\} + (1-v_i)\beta i, \text{ with } \beta, \kappa \geq 0, \tag{30}$$

where $w_u(1-\tau_u)$ is the net wage rate for worker that preserves the skill-type, while $w_s(1-\tau_s)$ is the net wage rate if skill-level improves. Since we assume no adjustment cost for high-skill workers to become low-skill workers and government sets below market skill-premium in the pre-transition period, we have only four types of workers. In the first group are young low-skill workers that decide to invest in human capital and earn net wage $w_s(1-\tau_s)(1-\kappa i)$. In the second group are middle-aged low-skill workers that do not invest in human capital, but decide to remain active and earn $w_u(1-\tau_u)$. In the third group are older workers that prefer inactivity as they receive sufficiently high non-employment benefits. The last group of workers are high-skill workers that earn $w_s(1-\tau_s)$ and have no incentive to make a change.[16] Workers with low human capital endowments compare indirect utilities of three competing options. As above, we assume that both the cost of investment in human capital as well as non-employment benefits increase with age (as indexed by i), ensuring that only the youngest individuals will choose to invest in their human capital, the oldest workers will become inactive, while the middle-aged workers will find it optimal to maintain both their skill-level and type of employment. The choice of the youngest workers to invest in education is driven entirely by the following condition:

16 The remaining alternatives are, of course, easily eliminated as educated workers (h) have no incentive to become inactive nor can they lose their human capital.

$$w_s(1-\tau_s)(1-\kappa i) \geq w_u(1-\tau_u) \text{ for } i \leq i_{us} \tag{31}$$

where i_{us} indexes the oldest worker still choosing to invest in skill improvements. On the other end of the distribution, the choice between continued work as low-skill worker and inactivity is governed by:

$$\beta i + \delta \geq w_u(1-\tau_u) \text{ for } i \geq i_c \tag{32}$$

where i_c denotes the worker that is indifferent between staying employed and becoming inactive.

Finally, the aggregate demand function, calculated as a sum of individual demand functions is simplified by the fact that the composite good price is set to one.

$$Q^d = \int_0^1 q_i^d \, di. \tag{33}$$

2.1.3 Government

We assume that government collects revenues by imposing a tax on gross wage and uses these either for gross wage subsidies or non-employment benefits. Thus, the balanced-budget constraint is:

$$\tau_s w_s L_s + \tau_u w_u L_u = \int_\Omega \beta i di, \tag{34}$$

where Ω denotes the set of inactive workers. As already noted, we assume that government cross-subsidizes wages of low-skilled workers in the pre-transition period in order to ensure low wage inequality. This is reflected in a positive tax rate on wage earned by high-skilled workers and a negative tax rate on wages earned by low-skilled workers. In transition period, government liberalizes wage determination and applies a common tax rate on gross wages in order to finance non-employment benefits.

2.2 Pre-transition equilibrium

We start with determination of pre-transition equilibrium. As before, we assume a stationary skill structure. In other words, labour income taxation in the pre-transition period is such that no low-skilled worker is better off by investing in additional human capital or moving to inactivity. This is true only when equality between net wage rates of low- and high-skilled workers holds:

$$w_{s1}(1-\tau_{s1}) = w_{u1}(1-\tau_{u1}) \tag{35}$$

and when the oldest low-skilled worker, who is entitled to the highest non-employment benefit, does not prefer to move to inactivity.

Besides relationship between net wages, the equilibrium is determined by the first order conditions from firms' profit maximization, labor market clearing condition and the balanced-budget constraint. The ratio between first-order conditions, (25) and (26), we get the relationship between employment shares of low- and high-skilled workers:

$$\frac{L_{u1}}{L_{s1}} = \frac{w_{u1}}{w_{s1}}\frac{1-\psi}{\psi}. \tag{36}$$

Combining (35) and (36), this ratio can be expressed as a function of tax rates:

$$\frac{L_{u1}}{L_{s1}} = \frac{1-\psi}{\psi}\frac{(1-\tau_{s1})}{(1-\tau_{u1})}. \tag{37}$$

While one of the tax rates can be set freely, the other one must be set in line with the balanced-budget constraint. In equilibrium, no low-skilled worker prefers inactivity to work, which simplifies the budget constraint to:

$$\tau_s w_s L_s + \tau_u w_u L_u = 0.$$

Using the relationship between gross wage rates (35) and the fact that the sum of low- and high-skilled workers equals to one:

$$L_{s1} + L_{u1} = 1, \tag{38}$$

we get a familiar relationship between the tax rates:

$$\tau_{s1} = -\frac{1-\psi}{\psi}\tau_{u1}. \tag{39}$$

We combine equations (37), (38) and (39) to calculate the shares of low- and high-skilled workers:

$$L_{u1} = 1-\psi(1-\tau_{s1}),$$

$$L_{s1} = \psi(1-\tau_{s1}).$$

The corresponding aggregate output is:

$$Q = K(1-\tau_{s1})^{\psi}(1-\psi(1-\tau_{s1}))^{1-\psi}, \tag{40}$$

where K is $\psi^{\psi}(1-\psi)^{1-\psi}$, the level of output in the case of no distortionary taxation.

In summary, in the pre-transition period government pursued the goal of low income inequality by using distortionary taxation. Higher tax rates on gross wages of high-skilled workers and thus higher subsidy rates on gross wages of low-skilled workers lead to lower share of high-skilled workers and higher share of low-skilled workers. However, an unwanted consequence of distortionary taxation was lower aggregate output.

2.3 Transition equilibrium

In transition period, government liberalizes wage setting by equalizing the tax rates on wages of two types of workers. For given pre-transition skill structure that corresponds to high tax rate on wage of high-skilled labour and low tax rate on low-skill labor, the tax rate equalization increases the skill premium. Therefore, some low-skilled workers now find alternative options, such as investing in human capital or becoming inactive, more attractive. In particular, since both costs of investment and non-employment benefits increase with age of workers, only young low-skilled workers decide to invest in human capital, middle-aged workers remain low-skilled and older low-skilled workers choose inactivity. Outflow of workers to inactivity and time spent in the process of education reduce the share of low-skilled workers. Consequently, aggregate output declines. In the remainder of this section, we derive the system of equations that determines this equilibrium.

We start by specifying the equilibrium relationship between the wage rates of two types of workers. As investment cost increases with age of workers, there exists a worker who is indifferent between investing in education and remaining active as a low-skill worker. For this worker, the net wage earned as high-skilled worker must be equal to the net wage earned as a low-skilled worker. Equality of tax rates simplifies (31) to:

$$w_{s2}(1-\kappa i_{us2}) = w_{u2}. \tag{41}$$

As before, the cost of education for the marginal worker that invests in education determines the skill premium. Note that the index of the marginal worker also equals to the share of workers that decide to invest in education.

On the other end of age distribution, there exists a low-skilled worker who is indifferent between moving to inactivity and staying active as a low-skill worker. From this condition, we get the relationship between net wages and government benefits:

$$\beta(i_{u1} - i_{ux2}) = w_{u2}(1-\tau_2) - \delta, \tag{42}$$

where $i_{u1} - i_{ux2}$ is an index of the youngest worker that chooses inactivity.

We now turn to final good market-clearing condition that equalizes the aggregate demand to the aggregate supply. The demand is a sum of individual demand functions for four groups of workers. In the first group are young low-skill workers that decide to invest in education. Their index ranges between 0 and i_{us2}, the index of the oldest worker that invests in education. These workers earn the wage rate of high-skilled workers, $(1-\tau_2)w_{s2}$, although they earn lower wage due to time used for schooling. In the second group are the middle-aged low-skilled workers that do not invest in education and thus earn $(1-\tau_2)w_{u2}$. Their index runs between i_{us2} and $i_{u1} - i_{ux2}$. In the third group are old low-skilled workers that have an option to receive high non-employment benefits. The index of these workers runs between $i_{u1} - i_{ux2}$ and i_{u1}. In the last group are all high-skilled workers. The aggregate demand for output good by these groups of workers is a sum of their after tax income:

$$Q_2^d = (1-\tau_2)\{w_{s2}(\int_0^{i_{us2}}(1-\kappa i)di + \int_{i_{u1}}^1 di) + w_{u2}\int_{i_{us2}}^{i_{u1}-i_{ux2}} di\} + \beta_2 \int_{i_{u1}-i_{ux2}}^{i_{u1}} i di, \tag{43}$$

which can be integrated to:

$$Q_2^d = (1-\tau_2)\{w_{s2}(1 - i_{u1} + i_{us2} - \kappa/2\, i_{us2}^2) + w_{u2}(i_{u1} - i_{ux2} - i_{us2})\} + \beta_2 i_{ux2}(i_{u1} - 1/2 i_{ux2}). \tag{44}$$

The aggregate supply is:

$$Q_2^s = L_{s2}^{\psi} L_{u2}^{1-\psi} = (1 - i_{u1} + i_{us2} - \kappa/2 i_{us2}^2)^{\psi} (i_{u1} - i_{ux2} - i_{us2})^{1-\psi}. \tag{45}$$

Using the arbitrage conditions (41) and (42) and the first-order conditions (26), we get the first of the two non-linear equations that determine the shares of workers that invest in skills and workers that become inactive:

$$(1-\tau_2)\left(1 + \frac{\delta i_{ux2}(i_{u1} - 1/2 i_{ux2})}{(1-\tau_2)(i_{u1} - i_{ux2})}\right) = Q_2\left(1 + \frac{(1-\psi)(1-\tau_2) i_{ux2}(i_{u1} - 1/2 i_{ux2})}{(i_{u1} - i_{us2} - i_{ux2})(i_{u1} - 1/2 i_{ux2})}\right) \tag{46}$$

The second equation is obtained from the balanced-budget constraint. This constraint is in transition period equal to:

$$\tau_2(w_{s2}L_{s2} + w_{u2}L_{u2}) = \beta_2 \int_{i_{u1}-i_{ux2}}^{i_{u1}} i di,$$

which can be further simplified using the arbitrage conditions (41) and (42) and the first-order conditions (26):

$$\frac{\tau_2}{1-\tau_2}\frac{i_{u1}-i_{ux2}}{i_{ux2}(i_{u1}-1/2i_{ux2})}=\frac{1-\psi}{i_{u1}-i_{us2}-i_{ux2}}-\frac{\delta}{(1-\tau_2)Q_2}. \tag{47}$$

The system of equations (46) and (47) determines the indices of marginal workers i_{us2} and i_{xu2}. From these we can determine the aggregate output and wage rates. Again, as this model yields no closed form solution, we analyze the model via simulations.

2.4 Analysis of the model

Analogous to the analysis of price liberalization we turn to a simulation exercise to study the implications of wage liberalization in transition. In order to determine the pre-transition equilibrium, we need to choose two parameters, the tax rate on skilled workers' wage τ_{u1} (or alternatively the tax rate on unskilled wages) and the weight of skilled in the production function, ψ. Table 3 summarizes the baseline parameter values, where the subsidy rate on unskilled labour is equal to 0.2, while the weight in production function is 0.4. Note that price level of final good is normalized to 1. Under the baseline parameter values the respective shares of skilled and unskilled workers are equal 0.720 and 0.280, while the output is 0.493. The preferential subsidies, given to unskilled labour, combined with the taxes on skilled labour, ensure that the net wages of all workers are the same. For the assumed values of parameters, the gross wages are equal to 0.33.

Using the pre-transition labour allocation, we can calculate the transition equilibrium by choosing the values of remaining parameters. The weight of leisure in the utility function (δ) is set to 0.3, the parameter that determines the distribution of cost of education (κ) to 2, while the common income tax rate in the transition period (τ_2) is 8%. Properties of the transition equilibrium are summarized in the bottom part of Table 4. A comparison of the pre-transition and transition equilibrium reveals that even though the size of the skilled labour force increases marginally, the size of the total labour force decreases from 1 to 0.816. This decline was brought on by a relatively large flow to inactivity (0.182), while the effect of the actual cost of 'vertical' labour mobility was marginal at best ($\kappa/2\, i_{us2}^2 = 0.0016$). The large outflow to inactivity (of unskilled workers) also adversely affects the production level, which declines from 0.493 to 0.416. The reallocation of labour from unskilled to either skilled labour or to inactivity is supported by a change in the gross wages of the two groups of workers. The net and gross wage of skilled are 0.489 and 0.532, respectively, while the corresponding wages of unskilled are 0.456 and 0.496.

We also consider how equilibria change in response to different parameter values. As before, we change value of one parameter, while keeping the values of remaining parameters unchanged. First, we start by increasing the subsidy given to unskilled gross wages from 0.200 to 0.300. This increases initial distortion to skill composition as the share of unskilled labour increases from 0.720 in the baseline case to 0.780 in this scenario.

The removal of those distortions in transition subsequently motivates greater mobility both from unskilled to skilled labor as well as to inactivity. While initial output is lower, also the size of output decline in transition period is lower in both absolute and relative terms. The share of workers moving to inactivity increases from 0.182 in the baseline example to 0.198, and the share of workers choosing to invest in skill improvements more than doubles. The decline of aggregate employment is, consequently, also larger, while an increase in inequality is larger.

Consider next an increase in the elasticity of substitution between two skill types from 0.40 to 0.50. This change causes slightly greater output decline and lower employment decline. This is a consequence of greater initial share of skilled workers, which do not need to invest in education and are not attracted to inactivity. Wage inequality is also smaller in this case, as non-employment benefits reduce unskilled to similar levels for skilled and unskilled workers. The remaining parameters have similar effects on output and employment dynamics as in the model with price liberalization. An increase of adjustment costs in the form of education and training reduces investments in skills and consequently increases output decline, while it increases wage inequality. Both increases in transition period tax rate and value of leisure lead to greater output decline and lower wage inequality, as more workers are attracted to inactivity.

Table 3: *Baseline parameter values*

Parameter	Description	Value
ψ	Elasticity of substitution in production	0.400
P_1	Pre-transition price	1.000
δ	Weight of leisure in utility function	0.300
τ_{u1}	Pre-transition subsidy rate on unskilled labor wages	-0.200
τ_{s1}	Pre-transition tax rate on revenue in sector y	0.300
τ_2	Transition tax rate on firms revenues	0.080
κ	Adjustment cost parameter	2.000

Table 4: *The equilibrium allocations and prices for the baseline parameter values and alternative assumptions*

	Baseline parameter values	Deviations from the baseline scenario				
		$\tau_{u1} = -0.30$	$\psi = 0.50$	$\kappa = 3.00$	$\tau_2 = 0.15$	$\delta = 0.4$
Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Q_1	0.493	0.470	0.490	0.493	0.493	0.493
L_{u1}	0.720	0.780	0.600	0.720	0.720	0.720
L_{s1}	0.280	0.220	0.400	0.280	0.280	0.280
$w_{s1} = w_{u1}$	0.330	0.261	0.370	0.330	0.330	0.330
Q_2	0.416	0.405	0.412	0.415	0.358	0.361
L_{us2}	0.034	0.074	0.009	0.029	0.001	0.002
L_{xu2}	0.182	0.198	0.175	0.185	0.290	0.294
$L_2 = L_{x2} + L_{y2}$	0.816	0.795	0.825	0.813	0.697	0.707
w_{s2}	0.532	0.562	0.504	0.539	0.511	0.512
w_{u2}	0.496	0.478	0.504	0.492	0.509	0.509
$\kappa / 2L_{xy2}^2$	$1.6 \cdot 10^{-3}$	$7.7 \cdot 10^{-3}$	$0.1 \cdot 10^{-3}$	$1.6 \cdot 10^{-3}$	$6.2 \cdot 10^{-7}$	$6.9 \cdot 10^{-6}$
β_2	0.291	0.241	0.367	0.285	0.316	0.172

Note: Columns (2)-(6) differ from the baseline scenario only in the value of parameter in the head of the table.

3 CONCLUSION

In this paper we develop two simple models that show how price and wage liberalization may have contributed to a part of the large aggregate output decline and an increase in income inequality in the early transition. The relationship between price liberalization and output decline is not a unique feature of our model (see Atkeson and Kehoe, 1996; Blanchard and Kremer, 1997; Roland and Verdier, 1999 and Gomulka and Lane, 2001), but rather the proposed mechanism, which is is consistent with a wide set of stylized facts relevant for the CEE countries.

We interpret initial distortions as direct political control over prices, wages and allocations and price liberalization as complete elimination of these distortions. In particular, we model price liberalization as a shift of preferences from those of social planners to preferences of consumers. These assumptions are in line with empirical evidence (Vodopivec, 1994), but contrast Gomulka and Lane (2001), who model price liberalization as elimination of distortionary tax system. An important problem of their interpretation is also in calculation of real GDP growth according to standard statistical methods, which may even exhibit growth of output.

According to our model, price liberalization alone is not sufficient for output decline. In order to comply with evidence on labor market flows during the early transition (Boeri and Flinn, 1999; Boeri, 2000a; Boeri and Terrell, 2002), we assume varying adjustment costs to labor mobility across different sectors and introduce non-employment benefits and reservation wage. Our explanation, however, differs from Atkeson and Kehoe (1996), who assume that adjustment costs are sufficiently low and investment horizon sufficiently long that workers are willing to bear adjustment costs. In their model, output decline is a consequence of investment in adjustment costs, which is inconsistent with observed low inter-firm, inter-sectoral and inter-occupational mobility and suggests that adjustment costs were not viable investments for the majority of workers. In addition to the interpretation of distortionary taxes, our model differs also from the other extreme model by Gomulka and Lane (2001), who assume prohibitive adjustment costs. Under this assumption alone, no worker would move between firms, which leads them to assume real wage rigidity. While this assumption is inconsistent with observed increase in wage inequality, it is also inconsistent with observed labour flows. If predetermined wages were indeed the cause of output decline, workers should have been forced to become inactive. Boeri (2000a) summarizes evidence that contradicts this assumption as labour flows were mostly voluntary. Hence, in our model, we assume that government provided non-employment benefits to workers and reservation wage earned in hidden economy. Both adjustment costs and non-employment benefits are positively related to age, which triggered young workers to move between sectors, middle-aged to stay in the same sector, while the oldest workers to become inactive. The decline of output and increased inequality are thus a consequence of trigger in the form of price liberalization and interplay between adjustment costs and non-employment benefits. The reduced labour supply due to increased inactivity leads also to aggregate output decline. In addition, wage liberalization that increased returns to education could alone be responsible for a part of decline as long as governments provided sufficiently high non-employment benefits.

We conclude with the following observation. Lack of firm- and individual-level data for the early transition period prevent us from empirically testing which of these explanations is the most plausible. Hence we cannot provide evidence on the relative importance of different supply-side and demand-side mechanisms. As it was argued already in Roland (2000), we cannot attribute the entire output decline to just one or the other mechanism. Hence, the aggregate demand shocks that worked either through expected income changes or trade embargos could be held responsible for a part of output decline. Nevertheless, consistency of our theoretical predictions with observed dynamics of sectoral employment and output, labor flows and wage inequality suggests that our proposed mechanisms may have played some complementary role in output decline. Hence we believe that transition governments, following typical Western European practice of offering generous nonemployment benefits (see Blöndal and Scarpetta, 1997; Nickell, 2004), can be held partly responsible for aggregate output decline that took place in the early transition.

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EXPLORATORY INNOVATION, EXPLOITATIVE INNOVATION AND INNOVATION PERFORMANCE: THE MODERATING ROLE OF ALLIANCE PARTNER DIVERSITY

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ABSTRACT: *Addressing the mixed findings in the literature, we distinguish between two distinct types of innovations, exploitative and exploratory innovations, and study their relationships with innovation performance. Organizational ambidexterity, the ability of a firm to simultaneously pursue both explorative and exploitative innovations, has been highlighted as increasingly important for the sustained competitive advantage of firms. By using the Community Innovation Survey 2006 micro data for innovation from twelve countries, we showed that simultaneously pursuing exploratory and exploitative innovation hinders firms' innovation performance. Furthermore, we proposed that firms' collaborations with different types of partners (suppliers, customers, competitors, research institutions and universities) would moderate the impact of exploitative and exploratory innovations on firm innovation performance differently. Our study also reveals that that the use of diverse collaborators is beneficial to the contradictory pressures for explorative and exploitative innovations.*

Keywords: *ambidexterity, exploration, exploitation, collaboration, alliance portfolio partner diversity, innovation performance*

JEL Classification: O30, D74, L25

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INTRODUCTION

A growing number of studies argue that successful firms cope with changing environments by being ambidextrous – able to simultaneously exploit their existing competencies and at the same time adapt to the changing environment by exploring new opportunities (Raisch, Birkinshaw, Probst, & Tushman, 2009). To respond to this environmental uncertainty, firms innovate. In the organizational learning literature, on which the distinction between the premises of exploration and exploitation are primarily grounded, this two activities are known as the two types of innovation (March, 1991). Exploitative innovation is crucial for short-term success, and because of its low level of uncertainty (Garcia & Calantone,

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2002), it is often preferable by firms because of its desirable outcomes, which are positive, proximate and predictable. Exploitative or incremental innovations are designed for existing customer and market needs (Danneels, 2004). However, long-term gains become questionable without exploration. Hence, explorative innovations are designed to produce new products that differ significantly from the existing ones and serve emerging markets and customers (Levinthal & March, 1993; March, 1991).

Firms' ability to simultaneously pursue both explorative and exploitative innovation is known as organizational ambidexterity (O'Reilly & Tushman, 2004). Consistent with the resource-based view, this ability is a key to superior firm performance because it exhibits rare attributes and thus enables a firm to gain and sustain a competitive advantage (Simsek, 2009). Although the performance effects of exploratory and exploitative innovation have drawn researchers' attention respectively, there is no strong and coherent support for a relationship between them (Gupta, Smith, & Shalley, 2006). Firms are faced with the struggle of how to sustain themselves on the turbulent market with the help of exploration or exploitation innovation or by ambidextrous innovation (Xu, 2015).

The prior literature recognized the importance of external knowledge for innovation. Past research found that exploring beyond organizational boundaries is more important than exploring within a firm (Rosenkopf & Nerkar, 2001). Other studies show that breadth of external knowledge sources contributes to the reconfiguration of the existing knowledge base (Kogut & Zander, 1992). On the other hand, scholars are still fuzzy on the pros and cons of exploratory and exploitative innovation effects, although simultaneous pursuit of both, the ambidextrous approach, has been more coherent and is often considered the optimal solution (Cao, Gedajlovic, & Zhang, 2009; He & Wong, 2004). For example, Lin and Chang (2015) showed that a higher level of ambidextrous innovation leads to better performance effects.

Yet, other scholars have found opposite effects of such relationships. A study showed that exploratory and exploitative innovations inhibit each other, as too much focus on either dimension of innovations may lead to poorer performance effects (Lavie & Rosenkopf, 2006). Moreover, because of the opposing nature of innovation activities, firms may reach better performance outcomes by balancing the two distinct dimensions of innovation across other dimensions (Lavie, Kang, & Rosenkopf, 2011; March, 1991; Zhang, 2016), such as with external relationships. Despite the proposal that firms' two distinct types of innovations may be sufficient for firm performance, Lavie and Rosenkopf (2006) and Zhang (2016) found empirical support that exploration and exploitation simultaneously lead to poorer performance outcomes. Therefore, an analysis of the interrelationships between often mutually exclusive innovation activities may be complemented by other dimensions beyond firms' boundaries, such as breadth of external diverse knowledge sources.

Thus scholars have recently identified external relationships, i.e., alliances, as drivers of exploration and exploitation innovation strategies, and conversely their joint effect has been examined. Scholars acknowledge the importance of managing firms alliance portfolio (Wassmer, 2010), and the fact that sets of multiple simultaneous alliances need to be carefully addressed and may not be individually managed (Lavie, Stettner, & Tushman, 2010). Recently, Castro and Roldán (2015) introduced the concept of alliance portfolio management which has three aspects, i.e., portfolio configuration, relationship management, and portfolio configuration, and acknowledge partner diversity as a valuable capability in managing an alliance portfolio.

Due to the increased technological change, the characteristics of portfolios (such as alliance portfolio partner diversity, hereafter APPD) have become more important but are still poorly understood (Faems, Van Looy, & Debackere, 2005; Oerlemans, Knoben, & Pretorius, 2013). The concept of alliance portfolio diversity, as one of the dimensions of alliance portfolio management, considers the heterogeneity of firms' direct external partners (Jiang, Tao, & Santoro, 2010; Oerlemans et al., 2013; Terjesen, Patel, & Covin, 2011; Wassmer, 2010). In general, a sample firm's ego network deals with how the actor, or "ego" (in our case the firm), is "tied" by some type of relationship with other actors (such as alliances). It has been argued as a key vehicle for accessing external resources that are not available within the boundaries of the firm (Lavie & Rosenkopf, 2006), either for exploitation innovation such as input quality improvements, or for cooperating with customers to reduce uncertainty when launching new products or services, i.e., explorative market introductions (de Leeuw, Lokshin, & Duysters, 2014). The main goal of alliance portfolio diversity (hereafter used interchangeably to refer to a wider range of terms such as APPD or breadth of knowledge sources) is to provide a firm with different resources and knowledge (de Leeuw et al., 2014), whether they are needed for the exploitative or explorative nature of innovations.

The performance implications of relationships between two distinct innovations and their interplay is the focal point of this research. The aim of this study is to address two key research questions: (1) How do the interrelationships between the distinct dimensions of innovations influence a firm's innovation outcomes, independently and simultaneously? (2) How do diverse external knowledge sources moderate that influence? Facilitating exploration and exploitation innovation activities may be quite demanding because of the high cost and risk concerns associated with exploration innovation (Uotila, Maula, Keil, & Zahra, 2009). Firms that simultaneously pursue exploratory innovation internally (or in-house) and opt toward optimization of type and number of partners externally (in some sense, they have a less diverse "exploitative" alliance portfolio) can confront an undesirable and perhaps unnecessary level of uncertainty and risk (He & Wong, 2004; Zhang, 2016).

Our study contributes to the literature in several different ways. First and foremost, we contribute to the organizational ambidexterity literature (Birkinshaw & Gupta, 2013) by studying the performance implications of a firm's engagement in both exploration and exploitation innovations. Our second potential contribution is to explore the nuanced effects of alliance portfolio partner diversity in a large dataset of innovative firms in twelve countries. The breadth of diverse knowledge sources has been shown by other authors to be a vehicle to access the external-party resources that are not otherwise available (Das & Teng, 2000; Zhang, 2016). A more heterogeneous or diverse portfolio of external partners can lead to a larger amount of information and resources, and as a corollary to the performance benefits (Wuyts & Dutta, 2014), too much diversity hinders the exchange and integration of information and resources (de Leeuw et al., 2014). Finally, we address this call and advance the international management research by using a broad dataset, namely the Community Innovation Survey (CIS) 2006 micro data for firm-level innovations obtained from twelve countries.

In the following paragraphs, we explain the theory with respect to (a) the relationship between exploration and exploitation innovation and innovation performance and (b) the effects of alliance portfolio partner diversity on this relationship, preceded by the data and methods section, which explains the empirical approach. The research results are reported and followed by a discussion and conclusion.

1 LITERATURE REVIEW AND HYPOTHESIS

1.1 Exploratory innovation and exploitative innovation

Prior research suggests that to sustain a competitive advantage, firms—besides possessing resources that are unique and inimitable—need to be ambidextrous (O'Reilly & Tushman, 2004). Ambidextrous firms are those that are able to exploit their existing competencies and at the same time avoid obsolescence by exploring new competencies (Leonard–Barton, 1991). Exploitation is associated with aspects such as efficiency and refinement, whereas exploration is related to notions such as variation and discovery (March, 1991). These aspects of exploration and exploitation concur with the dynamic capability view, which demands continuous reconfiguration and transformation of firm competences as an answer to environmental dynamism and market uncertainty (Eisenhardt & Martin, 2000). This represents a rather long-term, strategic view of management of firms' resources (Teece et al., 1997) as opposed to a short-term view on rapid combination and capitalization on them (Kogut & Zander, 1992). However, application of these concepts to innovation has remained ambiguous (Greve, 2007).

Our study suggests that exploration and exploitation as two types of distinct innovations may create substantial performance effects. Exploitative innovation creates value through firms' strengthening existing knowledge base and improvement of existing products or processes, whereas exploratory innovation creates value through firms' development of new domains or shift to different domains with the goal of adopting or creating new products or services (Ozer & Zhang, 2015). Firms need to invest considerable resources to develop exploratory innovation (de Leeuw et al., 2014). Thus exploratory innovations involve high levels of uncertainty (Garcia & Calantone, 2002), although the potential gains of such innovations are high (de Leeuw et al., 2014). While exploitation innovation as a low-risk strategy inhibits returns that are positive, proximate and predictable, exploratory innovation is uncertain and often high-risk, but potentially well rewarded (March, 1991).

Explorative innovations can give a firm the ability to cope with changing environments, open up new business opportunities and thus produce new products that differ significantly from existing ones (Levinthal & March, 1993; March, 1991), which are potentially important in order to harvest long-term gains. Hence exploratory innovations can facilitate innovation performance (Kang, Morris, & Snell, 2007), and firms with high levels of exploratory innovation focus appear particularly well suited to generate positive innovation outcomes. Engagement in exploitative innovations is typically associated with quality improvements, cost and time savings, and productivity gains (Baer & Frese, 2003; Klomp & Van Leeuwen, 2001), which is a necessary condition for achieving performance improvements in the short run. Therefore, both innovations can create positive synergies (Yang, Zheng, & Zhao, 2014).

Moreover, exploitative innovations buffer efficiency through constant reinforcement and improvement of a firm's current operations and product knowledge, whereas exploratory innovations stimulate innovations through the development of new knowledge (Jansen, Van Den Bosch, & Volberda, 2006; Ozer & Zhang, 2015). If a firm maintains high levels of both, it needs to invest a substantial amount of resources to introduce new processes and products and keep its operations efficient (Benner & Tushman, 2002). In turn, these processes that are not easily imitable pose barriers to rivals in the industry (Ho & Lu, 2015), and thus benefit the firm's performance outcomes. In summary, we hypothesize the following:

Hypothesis 1:
There is a positive relationship between exploratory innovation and a firm's innovation performance.

Hypothesis 2:
There is a positive relationship between exploitative innovation and a firm's innovation performance.

1.2 The interaction of exploration and exploitation innovation and its effects on innovation performance

The need for firms to engage in exploratory and exploitative innovation has been frequently emphasized (Birkinshaw & Gupta, 2013; O'Reilly & Tushman, 2013; Gupta et al., 2006), which raises the question of how to successfully balance them. Scholars have predominantly theorized and empirically supported two competing views of ambidexterity, i.e. the joint effects of exploration and exploitation. Following this dual logic of ambidexterity, present research differentiates between the complementary (combined) view (Cao et al., 2009; Cillo, De Luca, & Troilo, 2010; Lubatkin, Simsek, Ling, & Veiga, 2006; Simsek, Heavey, Veiga, & Souder, 2009), in which firms' efforts are directed toward increasing the complementary effect of exploratory and exploitative innovation, and the balanced view, the claim that balance between exploration and exploitation innovation exists when a firm pursues both types of innovation equally (Raisch et al., 2009) .

Although the advantages of exploratory and exploitative innovation are evident, as noted earlier, prior studies on the performance effects of the ambidextrous approach, whether from the balanced view or the combined view, have exhibited mixed results (Lavie et al., 2010). Scholars have empirically tested both the complementary effect and the balanced effect (Aspara & Tikkanen, 2013; Vorhies, Orr, & Bush, 2011). The complementary view regards exploration to complement exploitation or vice versa. It implies that exploration and exploitation add value to each other and offset each other's limitations to improve performance (Herhausen, 2016; Venkatraman, 1989). Moreover, exploration innovation helps to overcome the inadequacies of exploitation innovation, such as a firm's lack of ability to quickly adapt to market uncertainty. Conversely, exploitation innovation helps firms to improve and refine current skills and procedures (March, 1991) and thus enhances the effectiveness of exploration innovation in the attempt to address new changes.

Hypothesis 3a:
There is a complementary relationship between exploratory and exploitative innovations in improving a firm's innovative performance.

Although both dimensions of innovations are necessary for firm performance, pursuing both in equal proportion is nearly impossible (Bednarek, Burke, Jarzabkowski, & Smets, 2015) because their outcomes differ in terms of their "timing, and their distribution within and beyond the organization" (March, 1991, p. 71). Both innovation strategies are important to harvest performance gains, but if a firm decides to invest heavily in exploitation, this could result in missing important opportunities (March, 1991) or a situation in which it has fewer resources available for exploration (Stettner & Lavie, 2014). This yield to a trade-off situation is known as a competency trap (Levitt & March, 1988), suggesting that investment in exploitative activities drives out exploratory activities and vice versa, whereas exploration activities can lead to the ongoing search for new knowledge (Benner & Tushman, 2002).

Therefore, it is important that firms bridge the tendency overemphasizing exploitation by exploring new ideas and avoiding the so-called success trap (March, 1991; Rosenkopf & Nerkar, 2001). However, too much focus on exploration poses a problem as well; i.e., the failure trap. For instance, He and Wong (2004) found that imbalance between explorative and exploitative innovation strategies is negatively related to firms' performance. Moreover, the resource allocation trade-offs and conflicting organizational routines to which firms are exposed when they explore and exploit simultaneously in equal measure are likely to likely to lead to diminishing their performance (Stettner & Lavie, 2014). Gupta et al. (2006) argued that "the scarcer the resources needed to pursue both exploration and exploitation, the greater the likelihood that the two will be mutually exclusive—that is, high values of one will necessarily imply low values of the other" (p. 697). Rothaermel and Deeds (2004) in the context of strategic alliances showed that exploration alliances must be followed by exploitative alliances for successful introduction of new products or services. Hence, a lack or excess of focus on either dimension would have a negative impact on a firm's innovation performance.

Hypothesis 3b:
There is a balance (imbalance) between exploratory and exploitative innovations in improving a firm's innovative performance.

1.3 Moderating effects of alliance portfolio partner diversity

Although ambidexterity is essential for a firm's survival and prosperity (March, 1991), it is quite challenging to achieve within a single firm (Bednarek et al., 2015; He & Wong, 2004; Raisch & Birkinshaw, 2008). As a response to tensions between exploratory and exploitative innovations in pursuing ambidexterity internally, the use of external relationships in enabling ambidexterity has recently received much scholarly attention (Belderbos, Carree, Lokshin, & Sastre, 2015; Kauppila, 2010; Lavie et al., 2010). For instance, a firm that creates new products and technologies can harvest the benefits of balance by internally developing new advertising and distribution channels for its existing products that are familiar to the market. Hence, resources furnished via exploitation innovation internally can facilitate exploitation by external sources (Rothaermel, 2001). Furthermore, there is no resource spillover and firms can experience the enjoyable benefits of ambidexterity, which conversely enhances performance (Stettner & Lavie, 2014). Despite the growing interest in external relationships as a source of ambidexterity, current research largely neglects the alliance portfolio approach; i.e., interactions across a firm's portfolio.

Previous research highlights suppliers (Belderbos et al., 2015; Ho & Lu, 2015; Laursen & Salter, 2006; Takeishi, 2001) and/or clients as exploitative sources of knowledge and defines R&D institutes as exploratory ones. Universities give access to fundamental knowledge (Laursen & Salter, 2006), while suppliers possess knowledge that could lead to both valuable exploitative and exploratory innovation strategies (Sobrero & Roberts, 2002). Alliance with competitors gives access to industry-specific knowledge (Gnyawali & Park, 2011), whereas private research organizations can also be valuable sources (Oerlemans et al., 2013). While research acknowledges firms' alliance partners as potential sources of ambidexterity stimuli (Bednarek et al., 2015) that can reduce the tensions in the ambidexterity and ultimately enhance performance (Oerlemans et al., 2013), synergetic effects between diverse partners maintained by a firm, have been comparatively neglected. The diversity of alliance external relationships (i.e., partner types) can impact the firm performance beyond the effect of individual relationships (de Leeuw et al., 2014), and as such can be a valuable source for ambidexterity. For example, Lin and Chang (2015) found that technological diversification strongly interacts with absorptive capacity, and innovation performance is enhanced when higher technological diversification is accomplished by higher absorptive capacity. Thus, firms with a high level of absorptive capacity are able to relieve the tension caused by managing multiple and diverse collaborations.

Innovation performance is a result of exploratory innovations or an introduction and acceptance in the market of a firm's new products and services, which extends its competencies significantly (Voss, Sirdeshmukh, & Voss, 2008). Exploration innovations and consequently the generation of products and services preceding this performance ask for novel types of knowledge that are often unavailable in the innovating firm and only possessed by specific specialized external actors, such as specialized universities or lead users (Lettl, 2007). In other words, the creation of more exploratory breakthrough innovations requires an emphasis on access to scarce capabilities and expertise, and the possession of these is unequally distributed by very few specific types of partners.

Secondly, exploratory innovations are unpredictable and high risk. Most firms that pursue exploratory innovation might experience lack of capacity to absorb inflowing knowledge in such projects, and consequently, maintaining less diverse ties and focusing all their attention on those ties may be beneficial for exploratory innovation (Feller, Parhankangas, & Smeds, 2006; Oerlemans et al., 2013). This expectation is empirically supported in prior studies. For example, Hall and Bagchi-Sen (2007) find that in the biotechnology sector exploratory innovation is predominantly affected by one type of external relationships—universities. Similarly, Riggs and Von Hippel (1994) find that a vast number of innovations in the scientific instruments industry have come from lead users. Additionally, Feller et al. (2006) showed that exploratory innovators collaborated with fewer similar and complementary sets of external partners. Sampson (2007) found that exploratory innovations are driven by collaborations with moderate technological diversity. Hence we propose:

Hypothesis 4a:
The relationship between exploratory innovation and innovative performance is moderated by APPD. For firms with lower APPD, the relationship between exploratory innovation and innovation performance is more positive.

We further propose that alliance portfolio partner diversity will also strengthen the effect of exploitative innovation on innovation performance. We base this hypothesis on theory and research on an extended resource-based perspective (Lavie & Rosenkopf, 2006). The literature on the resource-based view of the firm (RBV) shows that firms collaborate with external partners in order to accompany their internal efforts (Deeds & Rothaermel, 2003) and describe how these resources can shape firm outcomes (Barney, 1991). It is likely that resources will vary between different partner type. Different relationships between different partner types can lead to diverse and non-redundant resources (Burt, 1992). For example, an alliance with a university or a research institute could lead to a new product or service, i.e., exploratory activity, while simultaneous alliance with suppliers can produce a development of new or significantly improved methods of manufacturing. In summary, theories of RBV and ambidexterity suggest that by employing increasing APPD, firms that pursue exploitative innovations obtain better innovation performance effects. Since the exploitative innovations entail fine-tuning of an existing product, process, or service for which a dominant design has already emerged and the innovation market expanded, the number of partner types with relevant knowledge increases (de Leeuw et al., 2014). Therefore, with the increasing level of APPD, firms can "handle" more diverse types of partners easily and benefit from their portfolio. More partner types have information that is valuable to the sample firms, and the sample firms therefore do not need to limit the collaboration to a few partner types (de Leeuw et al., 2014). For example, when an exploitative, motivated firm proceeds to perform the strategy of fine-tuning its existing capabilities, a more diverse APPD is likely to focus the firm's attention on further improvements of the existing possibilities that are the most useful for solving the firm's problems. We thus expect that higher levels of APPD will enhance the effect of exploitative innovation activities on innovation performance, and we propose the following hypothesis:

Hypothesis 4b:
For firms with higher APPD, the otherwise negative relationship between exploitative innovation and the firm's performance becomes positive.

2 METHODS

Sample

The hypotheses are tested with the Community Innovation Survey (CIS) 2006 micro data (company level). The data used for this survey cover the years 2004–2006. Anonymized data for the following countries were available and obtained centrally via Eurostat: Bulgaria, Cyprus, Czech Republic, Estonia, Norway, Portugal, Romania, United Kingdom, Slovakia, Slovenia, Spain and Switzerland. The CIS contains data concerning firms' innovation activities and engagement in alliances distinguished by partner type.

The subset was created by the following procedure. The first excluding question was "During the three years 2004 to 2006, did your enterprise co-operate on any of your innovation activities with other enterprises or institutions?" This question referred to collaboration that firms had had during a three-year period (2004 – 2006), while the measure of innovation performance included the year 2006 only. A similar procedure was done by Oerlemans et al. (2013). A key rationale for this lag is the "fact that it takes some time before the resources obtained through alliances find their way into innovative products and/ or services" (Oerlemans et al., 2013, p. 238). Secondly, if a firm indicated that it had maintained such a relationship, the respondent proceeded to the matrix table question, which was used to ask about multiple items in a single question. In this type of question respondents could indicate the type of innovation co-operation partner they worked with and it's geographical location. The matrix table question consisted of a 7 x 4 matrix (7 rows and 4 columns). Each row in this question (7 rows) represented a certain type of innovation co-operation partner, whereas each column further distinguished the type of partner by its geographical location. Specifically, four types of geographical location were distinguished: (1) respondent's country, (2) other European country, (3) the United States, and (4) all other countries.

Measures

Exploratory and Exploitative Innovations. Like most ambidexterity studies to date (He & Wong, 2004; Lubatkin et al., 2006; Tushman & O'Reilly, 1996), we frame our hypothesis in terms of firms' innovation orientation. To operationalize exploratory and exploitative innovations, we asked firms about the objectives of innovation in their firm, which required them to indicate the importance of the relevant objective on a four-point Likert scale representing "Not relevant," "Low," "Medium" and "High." Four objectives represent exploitation-oriented innovation strategy: "Improve quality of goods or services," "Improve flexibility for producing goods or services," "Increase capacity for producing goods or services" and "Reduce labor costs per unit output." Three objectives represented exploratory innovation: "Increase range of goods or services," "Enter new markets" and "Increase market share." Scores of 0, 1, 2 and 3 were allocated to responses on the four-point Likert scale for each objective (with 0 representing "not relevant" and 3 "high"); firms could therefore score a maximum of 12 points for exploitative-oriented innovation strategy and 9 points for exploratory-oriented innovation. We used the same approach as Archibugi, Filippetti, and Frenz (2013) and Derbyshire (2014).

Alliance Portfolio Partner Diversity. The CIS data contain information about the types of alliance partners and their geographical locations. We use a question from the CIS 2006 survey to distinguish whether the firm had any co-operation arrangement on innovation activities with other enterprises or institutions during the period of three years (2004–2006). After responding whether it had any innovation co-operation partnerships, it distinguished whether it had a partnership with one of the following actors: (1) other enterprises within its enterprise group, (2) suppliers, (3) clients or customers, (4) competitors, (5) consultants, commercial labs or private R&D institutes, (6) universities or other higher education institutes and (7) government or public research institutes. Firms were further asked to indicate whether their partner was located either in their home country or in the following geographical areas: another EU country, an EFTA or EU candidate country, the United States or other. Although the list was not fully comprehensive, it was extensive (Clausen, 2014).

In line with Oerlemans et al. (2013), APPD is calculated in several steps. Firstly, as conceptualization of APPD is based on the differences in partner types, and not primarily on the differences in their geographical location, we merged—the *four* lists of distinct partner types distinguished by location into *one* list. Our approach focuses on one aspect of alliance portfolio diversity—the diversity of types of alliances—and not on the diversity of partner types by geographical location. It is important to note that this measure does not indicate alliance portfolio size (de Leeuw et al., 2014). More diverse portfolios purely signal that a more diverse set of external actors possessing diverse knowledge sources are part of the ego network of the firm. Here, we focused on the sample firm's ego network, which included the firm (termed ego), and its direct inter-organizational ties with partners (termed alters) (Wasserman & Faust, 1994). Wassmer (2010) defined an alliance portfolio as the aggregate of all strategic alliances of a sample firm. In the network literature, an alliance portfolio is defined as a sample firm's egocentric alliance network; i.e., *all direct ties with partner firms* (Baum, Calabrese, & Silverman, 2000; Ozcan & Eisenhardt, 2009; Rowley, Behrens, & Krackhardt, 2000).

To capture the diversity of a firm's alliance portfolio we measured partner diversity by the Blau diversity index (1977). The Blau index of diversity has been widely used in the alliance literature (de Leeuw et al., 2014; Oerlemans et al., 2013) (Blau diversity index: $\mathrm{D} = 1 - \sum p_i^2$). The result of this calculation is a diversity score, a continuous variable that takes values between 0 (completely homogenous network or least diverse) and 1 (completely heterogeneous network or highest diversity where partners are equally dispersed among the categories). For example, if a firm has seven alliance partners, of which three are suppliers, two customers and two competitors, the Blau diversity index results in .65 $(1\text{-}(3/7)^2 + (2/7)^2 + (2/7)^2 = .65)$.

Innovation Performance. To operationalize innovation performance, we used items as measures of innovativeness that were developed within the Community Innovation Survey (CIS) (Brouwer & Kleinknecht, 1996). First, firms were asked to indicate whether they had introduced new or improved products or services in the previous two years (2004-

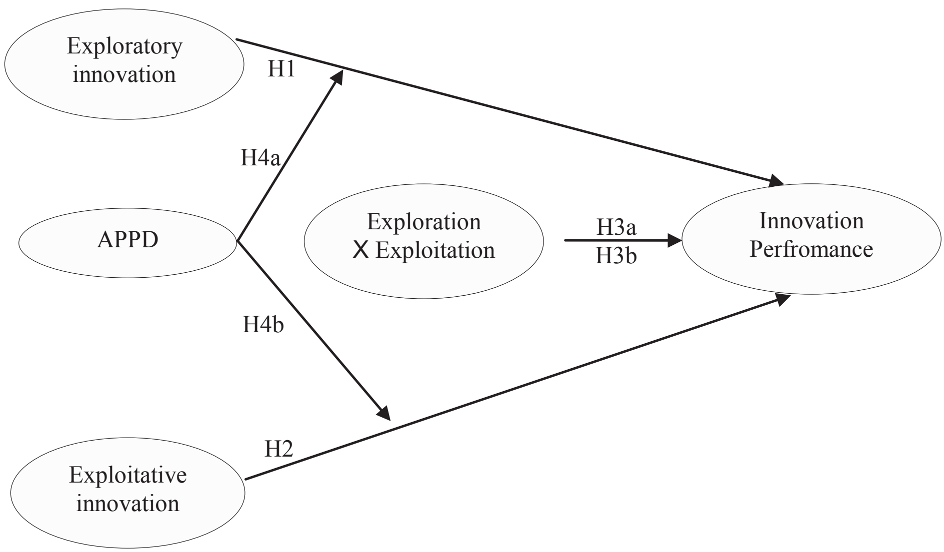
2006). To avoid bias resulting from measuring incidental innovation, a two-year period was chosen (Oerlemans et al., 2013). We used one variable to capture radical innovations and two variables as proxy for incremental innovations. The first variable was measured as the percentage of the firm's turnover (in 2006) generated from products or services that were technologically new to the world market, and the latter two expressed the percentage of the firm's turnover from products or services that were new to the firms and products or services that were significantly improved. We follow the approach of the previous studies that have conceptualized this variable using CIS data (Blindenbach-Driessen & Ende, 2014; Laursen & Salter, 2006), and this perception-based measure of innovation outcomes has shown to be highly reliable (Hagedoorn & Cloodt, 2003).

We included several *control variables* in the analysis. One of them was firm size, which was calculated as the logarithm of the number of employees in 2006. Prior studies find that innovation outcomes and inter-organizational collaborations are size-dependent, whereas larger firms have more abundant resources and it may be easier for them to handle multiple collaborative efforts, as well as multiple objectives of such relationships (Belderbos, Carree, & Lokshin, 2006; Belderbos et al., 2015; Cohen & Klepper, 1996). We also included a control variable that measured the number of factors hampering the firm's innovation activities. These factors hampering to innovation were controlled for because they were proxies for different types of bottlenecks to the firm's innovation activities and were likely to have a strong impact on the firm's decision to seek collaboration partners to overcome some of the bottlenecks (de Leeuw et al., 2014; Duysters & Lokshin, 2011). The "lack of quality personnel" or the "lack of financial resources" is one of *eleven* possible hampering factors, and firms were asked to assess their experience on one or more hampering factors listed on a four-degree importance scale of "high" (3), "medium" (2), "low" (1) or "no effect" (0). We used the same *additive* measure as (Černe, Jaklič, & Škerlavaj, 2013); i.e., the number of cases in which the respondent gave a positive response was *added*, resulting in a measure varying from 0 to 33 (for example, 11*3=33 was the maximum score).

We could not compare firms from different industries, given that different industries have different opportunities to innovate. We controlled the differences between the five NACE (Statistical classification of economic activities in the European Community) sectors. Following Černe et al. (2013), we dummy coded the firms as batch manufacturing, assembly manufacturing, construction and utilities, professional and financial services, and other services. In line with de Leeuw et al. (2014), we included a control variable for firms that were part of a domestic group. A dummy took the value of 1 (otherwise 0) if a firm had headquarters in another country. Prior research has shown that other members of a domestic group can have a similar influence on the innovativeness of a firm (de Leeuw et al., 2014). Experience in establishing and managing partnerships has been shown to be positively correlated with firms' ability to establish new alliance relationships (Dyer & Singh, 1998; Kale, Singh, & Perlmutter, 2000). Firms that are affiliates of a domestic group will have an advantage in such collaborative routines and accumulated experience relative to unallied firms. Moreover, firms may benefit from the technological knowledge available from their international headquarters (Isobe, Makino, & Montgomery, 2000). A control dummy for firms that are part of a domestic group is included.

Finally, we included the use of codified external information sources because these sources provide firms with external information and/or knowledge and can influence innovative performance (Oerlemans & Pretorius, 2006). We used the following question in the CIS questionnaire: "During the three years 2004 to 2006, how important to your enterprise's innovation activities were each of the following information sources?" This question distinguishes between three main groups of sources, i.e., *internal market sources institutional sources* and *other source*s. Respondents were asked to rate on a scale of 0 (not used) to 3 (very important) to what extent they used the three external information sources for technological innovations. Beside alliances, the use of codified external knowledge sources may be another source of external knowledge, which may have an influence on innovation outcomes and at the same time be a substitute for the use of alliance (Oerlemans & Pretorius, 2006). The control variable is calculated by taking the ratio of the total score and the maximum possible score (de Leeuw et al., 2014). In Table 1, we present the descriptive statistics and bivariate correlations for all variables. With regard to APPD, this table shows that the average APPD is 0.42, which corresponds to about four types of alliance partners (out of a possible seven). Figure 1 presents the conceptual model.

Figure 1: *Conceptual Model*



3 RESULTS

To test our hypotheses, we developed a set of models and tested them with multiple hierarchical linear regression analyses. In order to prevent any multicollinearity problems between the main effect variables and interaction effect variables, we mean-centered the variables before calculating the interaction terms (Aiken, West, & Reno, 1991).

First, the baseline model (Model 1, Table 2) with only the control variables was estimated. The use of external knowledge sources was positively associated with firms' innovation outcomes. The same premise held for the sectors in which firms were active (industry dummies), which were both positively related to firm innovation. Subsequently, the exploration and exploitation variables were added to the model (Model 2, Table 2). This addition led to a highly significant improvement of Model 2 in terms of variance explained; i.e., it demonstrated that these two variables increase the predictive power of Model 2 (ΔR^2 =0.13, F=184.19, $p < .01$). Model 2 also illustrates the effect of exploration and exploitation on firms' innovation performance.

Firstly, we added exploratory and exploitative innovation as the predictors of innovation performance. The results show a significant positive coefficient (b= .37, SE=.00, p < .01) for the exploratory innovation and a significant negative coefficient (b= -.07, SE=.00, p < .01) for exploitative innovation. These results support Hypothesis 1; however, the effect of exploitative innovation does not support our Hypothesis 2.

Model 3 shows interactive effects between exploration and exploitation on innovation performance and the moderating effect of APPD. First, we find that the interactions between exploration and exploitation are significantly and negatively associated with firms' innovation performance (b= -.07, SE=.00, p < .01). So our results provide support to H3b (i.e., a trade-off relationship), but not to H3a (i.e., a complementary relationship). Furthermore, we find support for the moderating effect of APPD. We find support for H4a, that the relationship between exploratory innovation and the innovation performance is more positive for firms with lower APPD (b= -.09, SE=.00, p < .01), and for H4b, the relationship between exploitative innovation and the firm's performance is a positive one for firms with higher APPD (b= .07, SE=.00, p < .01). In order to interpret the moderating effects of APPD, the relationship between exploration and exploitation and a firm's innovation performance is plotted in Fig. 2 and 3. What emerges from Fig. 2 and 3 is in line with the predicted effects. We examined the interaction effects between exploitative innovation and APPD to see whether APPD might soften the negative effect of exploitive innovation strategy on innovation performance. The results revealed that firms with diverse alliance partners have a positive relationship between exploitation and innovation performance (Fig. 3). In turn, Figure 2 showed that firms whose portfolios include a less diverse set of alliance partners have a more positive relation between exploratory innovation and innovation performance.

Exploitative innovation becomes less negative and statistically significant when we include the interaction effect in the analysis. This might indicate that firms with a higher level of APPD have a better innovation output. Given that the fine-tuning of the existing innovation (i.e., exploitation) is less complex, our results coincide with de Leeuw et al. (2014) research; if we want to improve our innovation performance, we need a broader portfolio that blends a broader set of actors. However, as exploration innovation requires a focus on the knowledge-base for adaption, it benefits from the limited number of partners (de Leeuw et al., 2014).

Table 1: Means, Standard Deviations, and Correlations[a]

	Variable	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12
1	Explorative innovation	4.20	3.27												
2	Exploitative innovation	4.97	3.84	$.61^{**}$											
3	Innovation performance	0.51	0.50	$.55^{**}$	$.33^{**}$										
4	Alliance portfolio partner diversity (APPD)	0.42	0.33	$.26^{**}$	$.21^{**}$	$.27^{**}$									
5	Firm size (log)	0.50	0.67	$.10^{**}$	$.15^{**}$	$.10^{**}$	$.18^{**}$								
6	Batch manufacturing	0.34	0.47	$.16^{**}$	$.12^{**}$	$.11^{**}$	$-.03^{*}$	$.01^{**}$							
7	Assembly manufacturing	0.13	0.34	$.13^{**}$	$.06^{**}$	$.10^{**}$	$.03^{*}$	$.04^{**}$	$-.28^{**}$						
8	Construction and utilities	0.06	0.23	$-.11^{**}$	$-.08^{**}$	$-.09^{**}$	.01	$.04^{**}$	$-.18^{**}$	$-.10^{**}$					
9	Other services	0.25	0.44	$-.08^{**}$	$-.09^{**}$	$-.04^{**}$	$-.03^{**}$	$-.09^{**}$	$-.42^{**}$	$-.23^{**}$	$-.14^{**}$				
10	Professional and financial services	0.13	0.34	$.02^{**}$	$-.06^{**}$	$-.03^{**}$	$.06^{**}$	$.02^{**}$	$-.28^{**}$	$-.15^{**}$	$-.10^{**}$	$-.23^{**}$			
11	Part of domestic group	0.23	0.42	$.09^{**}$	$.09^{**}$	$.04^{**}$	$.15^{**}$	$.34^{**}$	$-.06^{**}$	$.02^{**}$	.00	$-.03^{**}$	$.09^{**}$		
12	Innovation bottlenecks	11.56	8.30	$.23^{**}$	$.22^{**}$	$.10^{**}$	.02	$-.05^{**}$	$.12^{**}$	$.05^{**}$	$-.05^{**}$	$-.08^{**}$	$-.06^{**}$	$-.10^{**}$	
13	Use of codified knowledge sources	0.34	0.29	$.40^{**}$	$.38^{**}$	$.23^{**}$	$.30^{**}$	$.12^{**}$	$.02^{**}$	$.03^{**}$	$-.04^{**}$	$-.04^{**}$	$.03^{**}$	$.05^{**}$	$.15^{**}$

[a] n = 7808. $^{**}p < .01$, $^{*}p < .05$

Table 2: Moderation analyses for innovation performance as the explanatory mechanism[a]

Variables	Innovation performance		
	Model 1	Model 2	Model 3
Control variables			
Firm size (log)	.06** (.01)	.05** (.01)	.05** (.01)
Batch manufacturing	.31** (.02)	.23** (.02)	.22** (.02)
Assembly manufacturing	.34** (.02)	.24** (.02)	.24** (.02)
Construction and utilities	.05** (.03)	.06** (.03)	.06** (.03)
Other services	.18** (.03)	.13** (.02)	.13** (.02)
Professional and financial services	.28** (.02)	.19** (.02)	.19** (.02)
Part of domestic group	.02* (.01)	-.01(.01)	-.01(.01)
Innovation bottlenecks	-.02 (.00)	-.04** (.00)	-.04** (.00)
Use of codified knowledge sources	.20**(.02)	.06** (.02)	.06** (.02)
Independent variables			
Explorative innovation (x_1)		.37** (.00)	.37** (.00)
Exploitative innovation (x_2)		-.07** (.00)	-.02† (.00)
Alliance portfolio partner diversity (APPD)		.15** (.01)	.18** (.02)
Interaction effects			
APPD × Explorative innovation			-.09** (.00)
APPD × Exploitative innovation			.07** (.00)
$x_1 \times x_2$			-.07** (.00)
Adjusted R^2	.08	.20	.23
Δ Adjusted R^2		.13	.03
F-value	75,63	184,19	158,50
P-value	.00	.00	.00

[a]*Notes: Standard errors are in brackets. **p < .01, *p < .05, † p<.10*

Figure 2: *The moderating effect of alliance portfolio partner diversity on the exploration -innovation performance relationship*

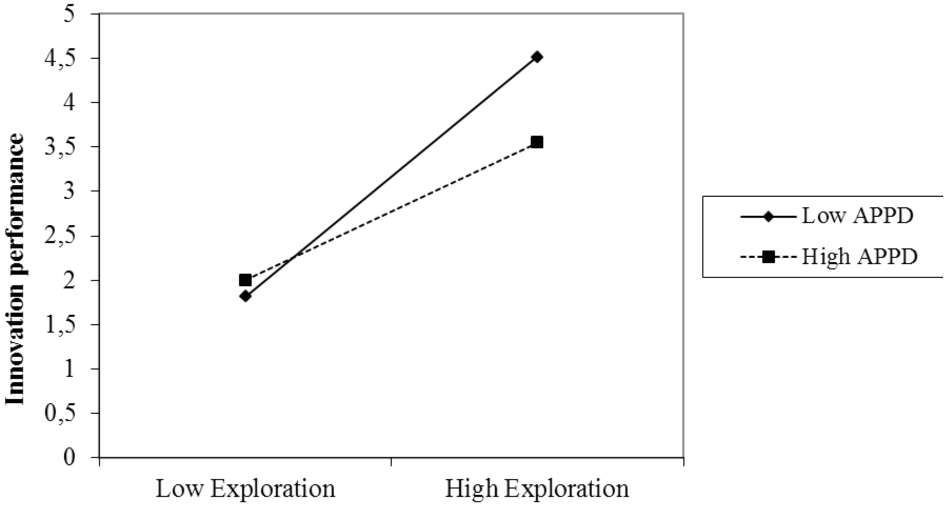
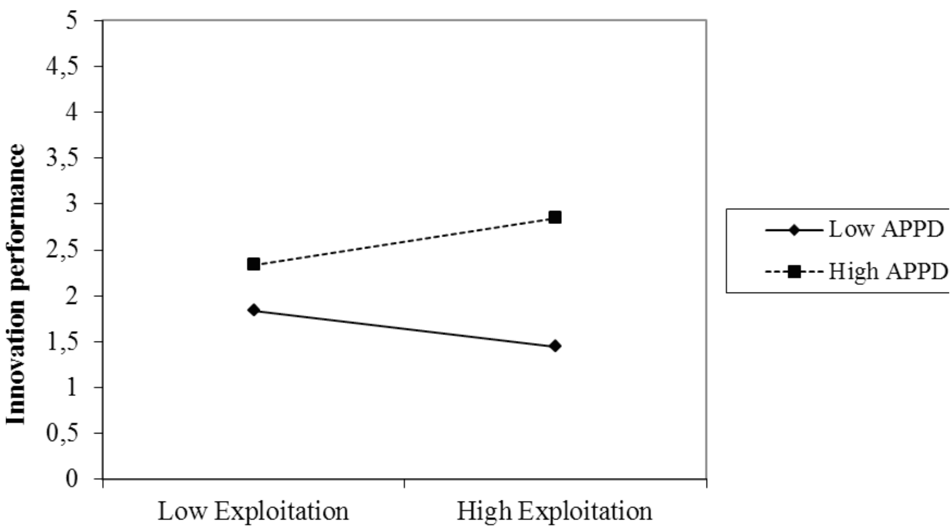


Figure 3: *The moderating effect of alliance portfolio partner diversity on the exploitation-innovation performance relationship*



4 DISCUSSION

Exploration involves developing new knowledge, while exploitation is based on refinement of existing knowledge (Rothaermel & Deeds, 2004). Both activities are essential for organizations, especially organizational performance. March (1991) in his seminal work discussed potential trade-offs of such activities. Most of the literature in the past decade has advocated *ambidexterity*, suggesting that firms could jointly explore and exploit. However, prior research has presented mixed evidence on the merits of ambidexterity. Our research underscores the premise that firms that pursue both exploration and exploitation can enhance their performance. This is consistent with the existing studies on the effects of exploration and exploitation on firm performance (Ebben & Johnson, 2005; Lavie et al., 2010; March, 1991). Moreover, our results suggest that there are inherent trade-offs between these activities; i.e., exploration and exploitation are mutually exclusive.

In line with our hypothesis, we found support for the moderating effect of APPD. Moreover, we hypothesized that firms with a high level of exploratory innovation activities benefit from the enhanced innovation outcomes in contexts that are characterized by lower rather than higher APPD. In turn, high levels of diversity are more suited for fostering exploitative innovation.

4.1 Contributions and Theoretical and Practical Implications

One of the reasons for the potential trade-off situation is the self-destructive nature of those adaptive processes (March, 1991) which may lead to a two-way scenario situation. Either a success (too much focus on exploitation) or a failure trap (too much focus on exploration) situation can lead to overemphasizing exploration or exploitation, eventually resulting in an imbalance (Levinthal & March, 1993). Leiponen and Helfat (2010) argued the potential limitation of having more innovation objectives, which amounted to a potentially unlimited number. Because of cumulative learning (Cohen & Levinthal, 1990), firms may encounter higher marginal cost due to the increased number of innovation objectives (Leiponen & Helfat, 2010), and therefore they may need to trade off the breadth and depth of such innovation objectives. Therefore, we argue that exploration and exploitation innovation objectives can be either complementary or mutually exclusive (they inhibit each other). To overcome an internal trade-off—i.e., a substitution relationship between firms' innovation objectives—external knowledge sources may serve as a key vehicle for balancing innovation objectives. Firms should analyze whether pursuing exploitation innovation objectives internally or exploration objectives in cooperation with others are more important for firm's specific goals. Although exploration objectives play a more important role in the long run for a firm, we want to emphasize that exploitation objectives are not less important. Tensions in innovation can trigger traps, cycles that stem from an increasingly one-sided focus on either exploration or exploitation (Andriopoulos & Lewis, 2010). Hence our study offers some important implications, such as that gravitating toward exploration might lead toward a "failure trap" (Gupta et al., 2006).

As Lavie et al. (2010) argued, exploration and exploitation need to be seen along multiple domains; e.g., exploration becomes more important for one stage of innovation, for instance developing exploration externally or via collaborations, and consequently it may buffer exploitation in another domain, such as internally. This is consistent with the ambidexterity premise, in which exploration provides a starting point for exploitative activities. The results of our study show that imbalance between exploratory and exploitative innovation leads to negative performance outcomes. Along with this fact, it is very possible that firms will not use external knowledge sources or will use broad and diverse ones at a low level. This is perhaps why low-diversity collaborators moderated the effectiveness of the exploratory innovation on performance. Therefore, our results suggest that firms should consider adopting broader and diverse knowledge sources when making decisions about which innovation objectives should be adapted internally or with the help of broader knowledge sources. Our study shows that performance implications from exploitation innovation need to be carefully managed. Firms need to try to leverage their current capabilities to try to prevent firms from being vulnerable to market and technological changes (Atuahene-Gima, 2005).

The prior research separately considered two dimensions of knowledge, breadth of knowledge sources—i.e., diversity of alliance external sources—and innovation objectives. From the knowledge resource perspective, this study finds that diverse knowledge sources contribute differently to the exploration-exploitation performance relationship. Along with the fact that exploration and exploitation are mutually exclusive, interesting results came when we take into account the breadth of diverse external alliance relationships. The findings in this study suggest that firms actually need to pay more attention to exploitation-related innovation objectives. That means that breadth of diverse knowledge sources should be pursued to a high level, while pursuit of exploitation innovation objectives should have more positive effect on innovations. A broad, diverse alliance portfolio provides a firm an opportunity to better leverage its flexibility (Xu, 2015). This is perhaps why broader diverse alliance partners positively moderated the effectiveness of exploitation-related innovation objectives on innovation performance. An additional reason may be found in combining breadth of diverse knowledge sources and complementary knowledge (Leiponen, 2005). As innovation often depends on recombining knowledge (Kogut & Zander, 1992; Schumpeter, 1934) and opting toward more diverse knowledge sources such as clients, suppliers could be beneficial to innovation performance (Leiponen & Helfat, 2010).

Our first theoretical contribution is aimed at the alliance management literature. Previous research has demonstrated that alliance portfolios have to be configured differently depending on the firm's priority with respect to exploratory and exploitative innovation strategies (de Leeuw et al., 2014). Our attempt to obtain a more accurate understanding of the examined multidimensional relationship has unfortunately failed to do so. Our study pointed at the importance of a narrower, more focused alliance partner portfolio diversity by which a firm can effectively pursue an exploratory innovation strategy.

The second theoretical contribution of our study addresses the gaps in the exploration/exploitation literature. Our results revealed that exploratory innovation positively affected firms' innovation performance. As this is not the case for exploitative innovation, a pre-press ambidexterity research asserted their trade-off relationship (Stettner & Lavie, 2014). To achieve this contribution, our research is rooted in the ambidexterity literature, which has argued different solutions to the exploration/exploitation dilemma (Stadler, Rajwani, & Karaba, 2014). In an attempt to add to the former discussion and research on ambidexterity, we challenge the merits of balancing exploration and exploitation within firms. Regardless of the impact that these two dimensions of innovation strategies have on the ambidexterity literature, the alliance portfolio management literature has proposed that the link between exploration and exploitation can be assessed as one of the dimensions of APD, namely functional diversity (e.g., the range of activities for which the firm uses alliances) (Jiang et al., 2010). Unfortunately, it has neglected the effects of other dimensions on innovation performance.

By contributing to the further advancement of the exploration-exploitation framework in different national contexts, we also made a contribution to the international management literature. As a large portion of our sample consists of international alliances (the CIS 2006 micro data: Bulgaria, Cyprus, Czech Republic, Estonia, Norway, Portugal, Romania, United Kingdom, Slovakia, Slovenia, Spain and Switzerland), we helped to understand the exploration-exploitation tensions along with a mixture of different industries and national contexts. Viewing the APPD not simply in a one-dimensional way provides firms with the ability to handle the complexity of the separation solution to the exploration/exploitation dilemma (Stadler et al., 2014).

What is more, this study has important practical implications. It informs innovation and alliance managers whether they should deploy diversity in their alliance portfolio and which levels of APPD are optimal to undertake in case of this deployment. Our study shows that high levels of a firm's exploration innovation activities might be particularly valuable for alliance portfolios with lower levels of partner diversity. This is particularly relevant for several reasons. Firstly, a firm that favors the balance of explorative and exploitative innovations is advised to pay extra attention when employing external knowledge, especially a diverse one. External knowledge for different innovation purposes, either to exploit or explore, can be overwhelming for firms at first. With regard to the latter, external and diverse knowledge can add much to a firm's innovation performance of exploitative innovation. A regular redesign of the alliance portfolio might help alliance mangers to improve their performance outcomes.

4.2 Limitations and Future Research

This study has several limitations that need to be taken into account in future research. First, this study did not test nonlinear effects of organizational ambidexterity on innovation performance. Although we did not formally hypothesize about this nonlinear effect, it would be interesting to further examine the dynamic between exploration and exploitation activities. Instead of looking at them as two parallel strategies and operationalizing them by multiplying (interaction), a worthwhile starting point would be to operationalize them as one variable and see their nonlinear relationship. Another limitation is operationalization of ambidexterity. In our study we use the multiplication approach, one of the three possible approaches to conceptualize ambidexterity, along with addition and absolute difference. However, a limitation of using the multiplication approach is that it does not determine whether exploration or exploitation contributes more to the magnitude of ambidexterity (Herhausen, 2016).

The same premise holds for the breadth of diverse external knowledge sources. We assume that exploration and exploitation can be substitutes or compliments—often depending on the nature of the operationalization of the concept. Finally, the results of our study show that the relationship between exploitative innovation and firm innovation performance is negative. However, these results could be a little skewed due to the measure of innovation performance (measured as a percentage).

Our study is limited to one dimension of the alliance portfolio management construct. First, alliance portfolio diversity is a multidimensional construct that includes partner, functional and governance diversity. We have theorized alliance portfolio diversity as the degree of variance in partners' purposes. Therefore the APD dimension only shapes a context with a limited impact on innovation. National diversity or industry diversity as part of alliance partner portfolio diversity is theorized, but we have not measured them directly. As an alliance portfolio can vary in diversity along these three dimensions, a future research could attempt to measure these aspects of alliance diversity altogether. Moreover, the study of the influence of these dimensions with respect to firms' explorative and exploitative innovations across different levels of analysis would present a valuable extension of this research.

Although the CIS data might be of a doubtful quality in terms of accuracy of exploration and exploitation innovation activity assessment as well as APPD construct, it leaves room for further research. Although the CIS data may have shortcomings, especially the time period of the sample (2004-2006), they are well accepted by different scholars in exploration/exploitation research as well as in alliance portfolio diversity research. Via the CIS data, it is possible to further validate the research on two streams, balancing exploration and exploitation across different levels and managing their transitions with respect to their alliance portfolio diversity. In other words, items provided in this broad scope survey allow us to test this multidimensional phenomenon. Another useful extension would be decoupling APPD in terms of weak ties (e.g., research institutes) vs. strong ties (e.g., trade shows, suppliers and customers) and see how it benefits organizational ambidexterity. Recently, Paliokaitė and Pačėsa (2015) showed that firms that opt for better explorative innovation outcomes need to pay attention to regularly scanning the environment by using both strong and weak tie sources. Another extension for further research would be to see how specific sets of external partners (strong vs. weak external sources) are related to explorative and exploitative innovation. Therefore, it would be valuable to see whether Granovetter's (1973) theory that weak ties are more effective for exploration innovation is confirmed.

5 CONCLUSION

The main objective of this study is to examine the impact of explorative and exploitative innovation as distinct objectives on firms' innovation performance. Using a multi-country database, we examined the direct effect of exploration- and exploitation-related innovation objectives on firms' innovation performance. In addition, we investigated their interaction—the ambidexterity premise—and how these relationships are moderated by the breadth of diverse external collaboration partners. In our analysis we show that an exploration innovation objective has a positive and linear relationship with innovation performance, while for exploitation objectives this relationship is negative and significant. We also find support for our ambidexterity premise that exploration and exploration inhibit each other in a trade-off relationship. The results also suggest that the positive effect of exploration innovation objectives on firms' innovation performance is strengthened when external knowledge sources is lower. However, the impact of exploitation-related innovation objectives becomes positive and more rewarding when external relationships are diverse. This study also contributes to the literature on exploration-exploitation ambidexterity. The findings show that partner diversity or breadth of knowledge sources (closely associated with exploration activities) (Xu, 2015) may interact with distinct types of innovation objectives in influencing innovation performance. This is especially important for exploitation activities and adds to the generalizability of the ambidexterity premise.

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OPTIMAL INVENTORY CONTROL WITH ADVANCE SUPPLY INFORMATION

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ABSTRACT: *It has been shown in numerous situations that sharing information between the companies leads to improved performance of the supply chain. We study a positive lead time periodic-review inventory system of a retailer facing stochastic demand from his customer and stochastic limited supply capacity of the manufacturer supplying the products to him. The consequence of stochastic supply capacity is that the orders might not be delivered in full, and the exact size of the replenishment might not be known to the retailer. The manufacturer is willing to share the so-called advance supply information (ASI) about the actual replenishment of the retailer's pipeline order with the retailer. ASI is provided at a certain time after the orders have been placed and the retailer can now use this information to decrease the uncertainty of the supply, and thus improve its inventory policy. For this model, we develop a dynamic programming formulation, and characterize the optimal ordering policy as a state-dependent base-stock policy. In addition, we show some properties of the base-stock level. While the optimal policy is highly complex, we obtain some additional insights by comparing it to the state-dependent myopic inventory policy. We conduct the numerical analysis to estimate the influence of the system parameters on the value of ASI. While we show that the interaction between the parameters is relatively complex, the general insight is that due to increasing marginal returns, the majority of the benefits are gained only in the case of ull, or close to full, ASI visibility.*

Keywords: *Operational Research, Inventory, Stochastic Models, Stochastic supply, Value of information*
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1. Introduction

Nowadays companies are facing difficulties in effectively managing their inventories mainly due to the highly volatile and uncertain business environment. While they are trying their

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best to fulfill the demand of their customers by using more or less sophisticated inventory control policies, their efforts can be severely hindered by the unreliable and limited deliveries from their suppliers. Due to the widespread trend of establishing plants overseas or outsourcing to specialists it has become increasingly more difficult for the companies to retain control over their procurement process. As the complexity of supply networks grows, so do the challenges and inefficiencies the companies are facing; orders get lost or are not delivered in full, shipments are late or don't arrive at all.

It has been well acknowledged both in the research community as well as by practitioners that these uncertainties can be reduced and better supply chain coordination can be achieved through the improved provision of information (Lee and Padmanabhan 1997, Chen 2003). While the performance of a supply chain depends critically on how its members coordinate their decisions, sharing information can be considered as the most basic form of coordination in supply chains (Austin et al. 1998, Manrodt et al. 2005). In light of this, the concept of achieving a so-called Supply Chain Visibility is gaining on importance, as it provides accurate and timely information throughout the supply chain processes and networks (Rassameethes et al. 2000, Jahre et al. 2007, Barratt and Adegoke 2007). This enables companies to share the information through often already established B2B communication channels and ERP solutions. EDI formatted electronic notifications on the status of the order fulfillment process, such as order acknowledgements, inventory status, Advance Shipment Notices (ASN), and Shipment Status Messages (SSM) are shared, enabling companies to track and verify the status of their order and consequently foresee supply shortages before they happen (Choi 2010). There are also multiple examples of companies like UPS, FedEx and others in shipping industry, and Internet retailers like eBay and Amazon, that are offering real time order fulfillment information also on the B2C level.

Real visibility in the supply chain can be regarded as a prerequisite for the companies to reach new levels of operating efficiency, service capabilities, and profitability for suppliers, logistics partners, as well as their customers. However, while the technological barriers to information sharing are being dismantled, the abundance of the available information by itself is not a guarantee for improved performance. Therefore the focus now is on developing new tools and technologies that will use this information to improve the current state of the inventory management practices.

In this paper, we investigate the benefits of advance supply information (ASI) sharing. We consider a retailer facing stochastic demand from the end customers and procuring the products from a single manufacturer with stochastic limited supply capacity. We assume that the order is replenished after a given fixed lead time, which constitutes of order processing, production and shipping delay. However it can happen that the quantity received by the retailer is less than what he ordered originally. This supply uncertainty can be due to, for instance, the allocation policy of the manufacturer, which results in variable capacity allocations to her customers or to an overall capacity shortage at certain times. This stochastic nature of capacity itself may be due to multiple causes, such as variations in the workforce (e.g. holiday leaves), unavailability of machinery or multiple products sharing the total capacity.

We assume that the manufacturer tracks the retailer's order evolution and at certain point, when she can assess the extent to which the order will be fulfilled, she shares ASI with the retailer, giving him feedback on the actual replenishment quantity ahead of the time of the physical delivery of products. ASI enables the retailer to respond to the possible shortage by adjusting his future order decisions, and by doing this possibly offset the negative impact of the shortage. Based on this rationale we pose the following two research questions: (1) How can we integrate ASI into inventory decision model, and subsequently characterize the optimal policy? (2) Can we quantify the value of ASI and establish the system settings where utilizing ASI is of most importance?

The practical setting in which the above modeling assumptions could be observed is food processing industry, where the food processing facilities/manufacturers are being supplied with the agricultural products. The products are harvested periodically and the product availability is changing through time depending on a variety of factors: weather, harvesting capacity, etc. Also it is reasonable to assume that supply capacity cannot be backordered as harvested products cannot be stored for longer periods. Khang and Fujiwara (2000) discuss this scenario for the frozen seafood industry, however they assume that the retailers' orders are fulfilled immediately by the manufacturer. We believe it is more realistic that the supply process is taking a number of time periods, more so that the process can be broken into two phases. As the order is made by the retailer, the harvesting part of the production process is underway, where the production outcome is uncertain. Then the products are delivered to the food processing facility. At this point the product availability is revealed and is no longer uncertain, and ASI is communicated to the customer in the form similar to ASN. The actual replenishment follows after the product is fully processed. This fully processed product can now also be stored.

Our work builds on the broad research stream of papers assuming uncertainty in the supply processes. In the literature the supply uncertainty is commonly attributed to one of the two sources: yield randomness and randomness of the available capacity. Our focus lies within the second group of problems, where Federgruen and Zipkin (1986a,b) were the first to address the capacitated stationary inventory problem with a fixed capacity constraint and have proven the optimality of the modified base-stock policy. Kapuscinski and Tayur (1998) extend this result by studying the non-stationary version of the model, where they assume periodic demand. Later, a line of research extends the focus to capture the uncertainty in capacity, by analyzing models with limited stochastic production capacity (Ciarallo et al. 1994, Güllü et al. 1997, Khang and Fujiwara 2000, Iida 2002). Ciarallo et al. (1994) explore different cases of the stochastic capacity constraint in a single and multiple periods setting. In the analysis of a single period problem, they show that stochastic capacity does not affect the order policy. The myopic policy of newsvendor type is optimal, meaning that the decision maker is not better off by asking for a quantity higher than that of the uncapacitated case. For a finite horizon stationary inventory model they show that the optimal policy remains to be a base-stock policy, where the optimal base-stock level is increased to account for the possible, however uncertain, capacity shortfalls in the future periods. Iida (2002) extends this result for the non-stationary environment.

Although a lot of attention in recent decades has been put in assessing the benefits of sharing information in the supply chains, the majority of the research is focused on studying the effect of sharing downstream information, in particular demand information (Gallego and Özer 2001, Karaesmen et al. 2003, Wijngaard 2004, Tan et al. 2007, Özer and Wei 2004). Review papers by Chen (2003), Lau (2007) and Choi (2010) show that sharing upstream information has been considered in the literature in the form of sharing lead time information, production cost information, production yield, and sharing capacity information. It has been shown by numerous researchers that information sharing decreases the bullwhip effect (the increasing variance of orders in a supply chain), however it was also shown that despite being optimal, the base-stock policy is an instigator of increased order variability (Jakšič and Rusjan 2008).

Capacity information sharing is of particular interest to our paper, where several papers have been discussing sharing information on future capacity availability (Jakšič et al. 2011, Altuğ and Muharremoğlu 2011, Çinar and Güllü 2012, Atasoy et al. 2012). Jakšič et al. (2011) study the benefits of sharing perfect information on future supply capacity available for orders to be placed in future periods. They show that the optimal ordering policy is a state-dependent base-stock policy characterized by the base-stock level that is a function of advance capacity information. Altuğ and Muharremoğlu (2011) work on a similar model; however they assume that the evolution of the capacity availability forecasts is done via the Martingale Method of Forecast Evolution (MMFE). The main difference in the way information is shared in the above cases compared to sharing ASI in this paper lies is the assumption about the time delay between the placement of the order and the time the information on the available supply capacity is revealed. In our case, the supply capacity information is revealed after the order has been placed and the lack of supply capacity availability results in the replenishment below the initial order. In the case of information about future capacity availability the order is aligned with this availability, and thus replenished in full. ASI thus only allows the decision maker to respond to the actual realized shortages in a more timely manner. While in the case of information on future capacity availability, the decision maker can anticipate the potential future shortages and accordingly adopt his ordering strategy. While in the latter case, the savings potential is higher, it is reasonable to assume that ASI is likely to be more reliable and easier to obtain in a practical setting.

Zhang et al. (2006) discuss the benefits of sharing advance shipment information. A setting in which a company receives the exact shipment quantity information is closely related to the one proposed in this paper, however they assume that inventory is controlled through a simple non-optimal base-stock policy and as such it fails to capture the uncertainty of supply. Our model can be considered as a generalization of the model by Zhang et al. (2006), as we allow for both, demand and supply capacity to be stochastic, and more importantly we model the optimal system behavior by considering considering the optimal inventory policy that is able to account for the supply uncertainty by setting appropriate safety stock levels. We propose that by having timely feedback on actual replenishment quantities through ASI, we can refine the inventory policy and improve its performance. To our knowledge the exploration of the relationship between the proposed way of modeling ASI and the optimal policy parameters has not yet received any attention in the literature.

Our contributions in this study are twofold. The focus is on modeling a periodic review single-stage inventory model with stochastic demand and limited stochastic supply capacity with the novel feature of improving the performance of the inventory control system through the use of ASI. Despite a relatively simple and intuitive structure of the optimal policy, the major difficulty lies in determining the optimal base-stock levels to which the orders should be placed. Already for the single-stage model under consideration, we need to resort to the numerical analysis to estimate these. Even more so, analyzing the real-life supply chains inevitably leads to the complex system state description, causing the state space to become large and eventually too large to evaluate all possible future scenarios or realizations. The problem commonly referred to as *"Curse of dimensionality"* (Puterman 1994). This greatly reduces the likelihood that a realistic inventory problem can be solved. One way to tackle this problem is to search for the approximate inventory policy, which comes at the cost of suboptimal performance. In our case we opt to analyze the myopic (shortsighted) inventory policy, and compare its parameters to the optimal ones.

In addition to the analytical and numerical results, we provide some relevant managerial insights related to optimal inventory control and the value of information sharing between the supply chain parties. The main dilemma in stochastic inventory management revolves around setting the appropriate safety stock levels, where the performance of the inventory system will depend on finding the right trade-off between the costs of holding the safety stocks and achieving the desired service level to the customers. While it is unrealistic that the companies would be able to integrate the proposed optimal policy into their ERP system, we provide some general guidelines on how the safety stock levels are influenced by the demand and supply uncertainty, and motivation for the companies to stimulate the information exchange with their supply chain partners.

The remainder of the paper is organized as follows. We present a model incorporating ASI and its dynamic cost formulation in Section 2. The optimal policy and its properties are discussed in Section 3. We proceed by the study of the approximate inventory policy based on the state-dependent myopic policy in Section 4. In Section 5 we present the results of a numerical study and point out additional managerial insights. Finally, we summarize our findings and suggest directions for future research in Section 6.

2. Model formulation

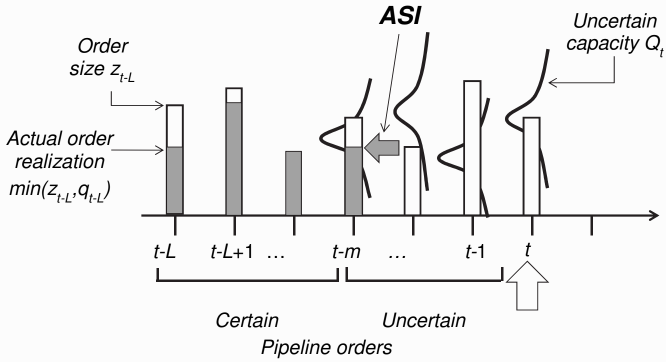
In this section, we introduce the notation and the model of advance supply information for orders that were already placed, but are currently still in the pipeline. The model under consideration assumes periodic-review, stationary stochastic demand, limited stationary stochastic supply with fixed supply lead time, finite planning horizon inventory control system. Unmet demand is fully backlogged. However, the retailer is able to obtain ASI on supply shortages affecting the future replenishment of the orders in the pipeline from the manufacturer. We introduce the ASI parameter m that represents the time delay in which ASI is communicated with the retailer. The parameter m effectively denotes the number of periods between the time the order has been placed with the manufacturer and the time ASI is revealed. More specifically, ASI on the order z_{t-m} placed m periods ago is revealed in period t after the order z_t is placed in the current period (Figure 1). Depending on the available supply capacity q_{t-m}, ASI reveals the actual replenishment quantity, determined as the minimum of the two, $\min(z_{t-m}, q_{t-m})$. We assume perfect ASI. Observe that the longer the m, the larger is the share of the pipeline orders for which the exact replenishment is still uncertain. Furthermore, we assume that the unfilled part of the retailer's order is not backlogged at the manufacturer, but it is lost. We give the summary of the notation in Table 1 and we introduce some later upon need.

Table 1: Summary of the notation

T	:	number of periods in the finite planning horizon
L	:	constant nonnegative supply lead time, a multiple of review periods ($L \geq 0$);
m	:	advance supply information parameter, $0 \leq m \leq L$
h	:	inventory holding cost per unit per period
b	:	backorder cost per unit per period
α	:	discount factor ($0 \leq \alpha \leq 1$)
x_t	:	inventory position in period t before ordering
y_t	:	inventory position in period t after ordering
$\tilde{x}_t$	:	starting on-hand inventory in period t
z_t	:	order size in period t
D_t	:	random variable denoting the demand in period t
d_t	:	actual demand in period t
Q_t	:	random variable denoting the available supply capacity at time t
q_t	:	actual available supply capacity limiting order z_t given at time t, for which ASI is revealed m periods later

We assume the following sequence of events. (1) At the start of period t, the decision maker reviews the current inventory position x_t. (2) The ordering decision z_t is made up to uncertain supply capacity and correspondingly the inventory position is raised to $y_t = x_t + z_t$. (3) Order placed in period $t - L$ is replenished in the extent of $\min(z_{t-L}, q_{t-L})$, depending on the available supply capacity. ASI on the order placed in period $t - m$ is revealed, which enables the decision maker to update the inventory position by correcting it downward in the case of insufficient supply capacity, $y'_t = y_t - (z_{t-m} - q_{t-m})^+$, where $(x)^+ = max(x, 0)$.

Figure 1: Advance supply information.



(4) At the end of the period previously backordered demand and demand d_t are observed and satisfied from on-hand inventory; unsatisfied demand is backordered. Inventory holding and backorder costs are incurred based on the end-of-period on-hand inventory.

Due to positive supply lead time, each of the orders remains in the pipeline stock for L periods. For orders placed m periods ago or earlier we have already obtained ASI, while for more recent orders the supply information is not available yet. Therefore we can express the inventory position before ordering x_t as the sum of net inventory and the certain and uncertain pipeline orders:

$$x_t = \tilde{x}_t + \sum_{s=t-L}^{t-m-1} \min(z_s, q_s) + \sum_{s=t-m}^{t-1} z_s. \tag{1}$$

Note, that due to perfect ASI the inventory position x_t reflects the actual quantities that will be replenished for the orders for which ASI is already revealed, while there is still uncertainty in the actual replenishment sizes for recent orders for which ASI is not known yet.

Observe also that m denotes the number of uncertain pipeline orders. Therefore, m lies within $0 \leq m \leq L$, and the two extreme cases can be characterized as:

- $m = L$, or so-called *"No information case"*, which corresponds to the most uncertain setting as the actual replenishment quantity is revealed no sooner than at the moment of actual arrival. This setting is a positive lead time generalization of the Ciarallo et al. (1994) model.

- $m = 0$, or so-called *"Full information case"*, which corresponds to the full information case, where before placing the new order, we know the exact delivery quantities for all pipeline orders. This is the case with the least uncertainty within the context of our model. Observe however that the current order is still placed up to uncertain supply capacity.

When moving from period t to $t+1$, we obtain ASI for the order z_{t-m} placed in period $t-m$. Correspondingly, the inventory gets corrected downwards if the order exceeds the available supply capacity, thus inventory position x_t is updated in the following manner:

$$x_{t+1} = x_t + z_t - (z_{t-m} - q_{t-m})^+ - d_t. \tag{2}$$

Note, that there is dependency between the order quantity and the size of the correction of x_t. If z_t is high, it is more probable that the available supply capacity will restrict the replenishment of the order, thus the correction will be bigger, and vice versa for low z_t. To fully describe the system behavior, we do not only need to keep track of x_t, but also have to track the pipeline orders for which we do not have ASI yet. We denote the stream of uncertain pipeline orders with the vector $\vec{z}_t = (z_{t-m}, z_{t-m+1}, \ldots, z_{t-2}, z_{t-1})$. In period $t+1$, $\vec{z}_{t+1}$ gets updated by the inclusion of the new order z_t, and the order z_{t-m} is dropped out as its uncertainty is resolved through the received ASI.

A single period expected cost function is a function of x_t and all uncertain orders, including the most recent order z_t, given in period t. Cost charged in period $t+L$, $\tilde{C}_{t+L}(\tilde{x}_{t+L+1})$, reassigned to period t when ordering decision is made, can be expressed as:

$$C_t(y_t, \vec{z}_t, z_t) = \alpha^L E_{\vec{Q}_t, Q_t, D_t^L} \tilde{C}_{t+L}(y_t - \sum_{s=t-m}^{t} (z_s - Q_s)^+ - D_t^L), \tag{3}$$

where the expected inventory position after ordering (accounted for the possible future supply shortages), $E_{\vec{Q}_t, Q_t}(y_t - \sum_{s=t-m}^{t} (z_s - Q_s)^+)$, is used to cover the lead time demand, $D_t^L = \sum_{s=t}^{t+L} D_s$.

The minimal discounted expected cost function, optimizing the cost over a finite planning horizon T, from time t onward, and starting in the initial state $(x_t, \vec{z}_t)$, can therefore be written as:

$$f_t(x_t, \vec{z}_t) = \min_{x_t \le y_t} \{C_t(y_t, \vec{z}_t, z_t) + \alpha E_{D_t, Q_{t-m}} f_{t+1}(y_t - (z_{t-m} - Q_{t-m})^+ - D_t, \vec{z}_{t+1})\}, \text{ for } t \le T, \tag{4}$$

where $f_{T+1}(\cdot) \equiv 0$. The cost function f_t is a function of inventory position before ordering and orders given in last m periods, for which ASI has not yet been revealed.

3. Analysis of the optimal policy

In this section, we show the necessary convexity results of the relevant cost functions. This allows us to establish the structure of the optimal policy and show some of its properties.

Lets define J_t as the cost-to-go function of period t:

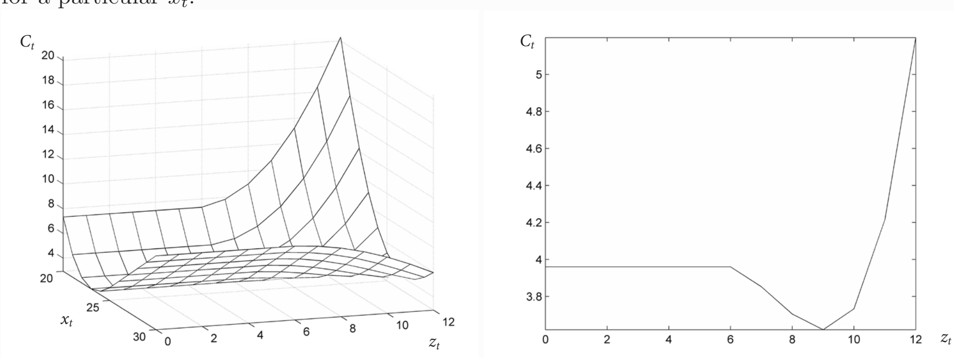
$$J_t(y_t, \vec{z}_t, z_t) = C_t(y_t, \vec{z}_t, z_t) + \alpha E_{D_t, Q_{t-m}} f_{t+1}(y_t - (z_{t-m} - Q_{t-m})^+ - D_t, \vec{z}_{t+1})\}, \text{ for } t \leq T. \quad (5)$$

The minimum cost function f_t defined in (4) can now be expressed as:

$$f_t(x_t, \vec{z}_t) = \min_{x_t \leq y_t} J_t(y_t, \vec{z}_t, z_t), \text{ for } t \leq T, \quad (6)$$

We proceed by establishing the necessary convexity results that allow us to establish the structure of the optimal policy. Observe that the single period cost function $C_t(y_t, \vec{z}_t, z_t)$ is not convex already for the zero lead time case as was originally shown by Ciarallo et al. (1994). $C_t(y_t, z_t)$ is shown to be convex in y_t and quasiconvex in z_t (Figure 2), which however still suffice for the optimal policy to exhibit the structure of the base-stock policy.

Figure 2: (a) $C_t(y_t, \vec{z}_t, z_t)$ as a function of x_t and z_t, and (b) $C_t(y_t, \vec{z}_t, z_t)$ as a function of z_t for a particular x_t.



We show that the results of the zero lead time case can be generalized to the positive lead time case, where the convexity of the costs functions in the inventory position is established given a more comprehensive system's state description $(x_t, \vec{z}_t)$. In Lemma 2 in the Appendix, we show that the single period cost function $C_t(y_t, \vec{z}_t, z_t)$ is not a convex function in general, but it exhibits a unique, although state-dependent, minimum. Based on this result one can show that the related multi-period cost functions $J_t(y_t, \vec{z}_t, z_t)$ and $f_t(x_t, \vec{z}_t)$ are convex in the inventory position y_t and x_t respectively (we show in Appendix that the convexity holds also for other characterizations of the inventory position), as shown in the next Lemma:

Lemma 1 *For any arbitrary value of information horizon m, value of the ASI vector $\vec{z}_t$ and the order z_t, the following holds for all t:*

1. *$J_t(y_t, \vec{z}_t, z_t)$ is convex in y_t,*

2. *$f_t(x_t, \vec{z}_t)$ is convex in x_t.*

Based on the results of Lemma 1, we establish a structure of the optimal policy in the following Theorem:

Theorem 1 *Assuming that the system is in the state $(x_t, \vec{z}_t)$, let $\hat{y}_t(\vec{z}_t)$ be the smallest minimizer of the function $J_t(y_t, \vec{z}_t, z_t)$. For any $\vec{z}_t$, the following holds for all t:*

1. *The optimal ordering policy under ASI is the state-dependent base-stock policy with the optimal base-stock level $\hat{y}_t(\vec{z}_t)$.*

2. *Under the optimal policy, the inventory position after ordering $y_t(x_t, \vec{z}_t)$ is given by*

$$y_t(x_t, \vec{z}_t) = \begin{cases} x_t, & \hat{y}_t(\vec{z}_t) \leq x_t, \\ \hat{y}_t(\vec{z}_t), & x_t < \hat{y}_t(\vec{z}_t). \end{cases} \tag{7}$$

The proof is by induction, where we provide the details in the Appendix. The optimal inventory policy is characterized by a single optimal base-stock level $\hat{y}_t(\vec{z}_t)$ that determines the optimal level of the inventory position after ordering. The optimal base-stock level however is state-dependent as it depends on uncertain pipeline orders $\vec{z}_t$, for which ASI has not yet been revealed. Observe that due to not knowing the current period's capacity, we are not limited in how high we set the inventory position after ordering. The logic of the optimal policy is such that y_t should be raised to the optimal base-stock level $\hat{y}_t$, although in fact y_t does not reflect the actual inventory position as it is possible that the order will not be delivered in its full size.

In a stationary demand and capacity setting, the base-stock levels are increased above the normal inventory level required to satisfy the expected demand. By doing so the extra inventory in the form of safety stock is kept to account for the uncertainty in future demand and supply. The uncertainty can lead to demand/supply mismatches, and correspondingly to increased inventory holding and backorder costs. In the context of our model, the dependency

Table 2: Optimal base-stock levels $\hat{y}_t(z_{t-2}, z_{t-1})$ ($L = 2$, $m = 2$, $E[D] = 5$, $CV_D = 0$, $E[Q] = 6$, $CV_Q = 0.33$)

	z_{t-1}									
z_{t-2}	0	1	2	3	4	5	6	7	8	9
0	20	20	20	20	20	20	21	22	23	24
1	20	20	20	20	20	20	21	22	23	24
2	20	20	20	20	20	20	21	22	23	24
3	20	20	20	20	20	20	21	22	23	24
4	20	20	20	20	20	21	21	22	23	24
5	20	20	20	20	21	21	22	23	**23**	24
6	21	21	21	21	21	22	22	23	24	25
7	22	22	22	22	22	23	23	24	25	25
8	23	23	23	23	23	**24**	24	25	25	26
9	24	24	24	24	24	24	25	25	26	27

of the optimal base-stock level on $\vec{z}_t$ can be intuitively attributed to the following; if we have been placing high orders (with regards to expected supply capacity available) in past periods, it is likely that a lot of the orders will not be realized in their entirety. This leads to probable replenishment shortages and demand backordering due to insufficient inventory availability. Therefore it is rational to set the optimal base-stock level higher with a goal of taking advantage of every bit of available supply capacity in the current period. By setting high targets, we aim to get the most out of the capacity, that is, we want to take advantage of periods with high supply availability, although the chances that it will actually be realized can be small. If currently, we are not facing supply shortages the tendency to use the above logic diminishes. The result is also confirmed in Table 2, where we see that the optimal base-stock level is increasing with increasing uncertain pipeline orders z_{t-1} and z_{t-2}.

4. Insights from the myopic policy

We proceed by establishing the approximate inventory policy that would capture the relationship between the uncertain pipeline orders and the target inventory position. While the optimal policy is obtained through a minimization of the multi-period cost-to-go function J_t as given in (5), the approximate policy is a solution to a single-period cost function $C_t(y_t, \vec{z}_t, z_t)$ as given in (3), thus we can refer to it as a myopic solution. The resulting structure of the myopic policy is equivalent to the structure of the optimal policy as presented in Part 2 of Theorem 2; however the orders are placed up to myopic base-stock levels $\hat{y}_t^M(\vec{z}_t)$, rather than optimal base-stock levels $\hat{y}_t(\vec{z}_t)$. Observe that $\hat{y}_t^M(\vec{z}_t)$ are also state-dependent on the uncertain pipeline orders $\vec{z}_t$, thus the myopic policy is able to account for the possible shortage in supply of the current pipeline orders. A detailed derivation of the myopic solution is provided in Lemma 2 in the Appendix.

While it would be great if myopic policy would provide a reliable estimate of the optimal costs, one can easily see that the myopic policy cannot account for future supply shortages (that is for the orders that are still to be placed in the future). This holds particularly for highly utilized system settings and in the case of high demand/supply capacity uncertainty that leads to probable demand and supply mismatches. Thus, the following study is primarily concerned with capturing the state-dependency of the optimal base-stock levels by exploring the relationship between the vector of uncertain pipeline orders and the corresponding approximate base-stock levels.

In Table 3 we present the base-stock levels for the optimal policy, myopic policy and the differences between the two. Both, the optimal and the myopic, base-stock levels were determined through the numerical analysis by minimizing the relevant multi-period and single period cost functions as mentioned above. Note that myopic policy is optimal when there is no supply capacity uncertainty (which corresponds to a base-stock level of 23). Looking at the differences between the base-stock levels we see that the myopic base-stock levels are always lower and thus can be regarded as a lower bound for the optimal base-stock levels. The differences are decreasing with increasing uncertain pipeline orders. This can be attributed to the fact that myopic policy accounts for the potential shortages in the replenishment of the pipeline orders, but fails to account for future supply unavailability. For high uncertain pipeline orders, the additional inventory to cover the supply shortage is sufficient to cover the risk of future shortages. in fact, we observe a risk pooling effect, where the base-stock level of 29 is sufficient to cover both risks.

5. Value of ASI

In this section we estimate the extent of the savings gained through incorporating ASI into the inventory system. We perform a numerical analysis to quantify the value of ASI and assess the influence of the relevant system parameters. Numerical calculations were done by solving the dynamic programming formulation given in (4).

To determine the influence of ASI parameter m, demand uncertainty, supply capacity uncertainty, and system utilization on the value of ASI, we set up the base scenario that is characterized by the following parameters: $T = 10, L = 3, \alpha = 0.99$ and $h = 1$ and

Table 3: The myopic and optimal base-stock levels, ($L = 2$, $m = 2$, $E[D] = 5$, $CV_D = 0.5$, $E[Q] = 6$, $CV_Q = 0.33$)

Myopic	z_{t-1}									
z_{t-2}	0	1	2	3	4	5	6	7	8	9
0	23	23	23	23	23	23	24	24	25	26
1	23	23	23	23	23	23	24	24	25	26
2	23	23	23	23	23	23	24	24	25	26
3	23	23	23	23	23	23	24	24	25	26
4	23	23	23	23	23	23	24	25	25	26
5	23	23	23	23	23	24	24	25	26	27
6	24	24	24	24	24	24	25	25	26	27
7	24	24	24	24	25	25	25	26	27	28
8	25	25	25	25	25	26	26	27	28	29
9	26	26	26	26	26	27	27	28	29	29
Optimal	z_{t-1}									
z_{t-2}	0	1	2	3	4	5	6	7	8	9
0	27	27	27	27	27	27	27	28	29	29
1	27	27	27	27	27	27	27	28	29	29
2	27	27	27	27	27	27	27	28	29	29
3	27	27	27	27	27	27	27	28	29	29
4	27	27	27	27	27	27	28	28	29	29
5	27	27	27	27	27	27	28	29	29	29
6	27	27	27	27	28	28	28	29	29	29
7	28	28	28	28	28	29	29	29	29	29
8	29	29	29	29	29	29	29	29	29	29
9	29	29	29	29	29	29	29	29	29	29
Difference	z_{t-1}									
z_{t-2}	0	1	2	3	4	5	6	7	8	9
0	4	4	4	4	4	4	3	4	4	3
1	4	4	4	4	4	4	3	4	4	3
2	4	4	4	4	4	4	3	4	4	3
3	4	4	4	4	4	4	3	4	4	3
4	4	4	4	4	4	4	4	3	4	3
5	4	4	4	4	4	3	4	4	3	2
6	3	3	3	3	4	4	3	4	3	2
7	4	4	4	4	3	4	4	3	2	1
8	4	4	4	4	4	3	3	2	1	0
9	3	3	3	3	3	2	2	1	0	0

$b = 20$. A discrete uniform distribution is used to model demand and supply capacity where the expected demand is given as $E[D] = 4$ and the expected supply capacity varies $E[Q] = \{4, 6, 8\}$, which means that the utilization of the system is $Util = \{1, 0.75, 0.5\}$. In addition we vary the coefficient of variation of demand $CV_D = \{0, 0.65\}$ and supply capacity $CV_Q = \{0, 0.33, 0.65\}$, and the ASI parameter $m = \{3, 2, 1, 0\}$, covering both the *No information* and *Full information* case.

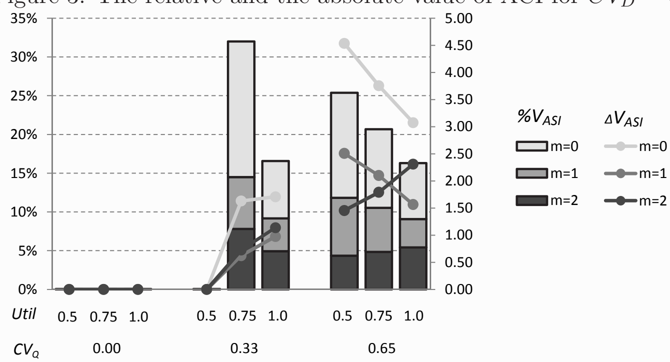
We define the relative value of ASI for $m \leq L$, $\%V_{ASI}$, as the relative difference between the optimal expected cost of managing the system in the *No information* case ($m = L$), and the system where we have obtained ASI on a number of pipeline orders ($m \leq L$):

$$\%V_{ASI}(m \leq L) = \frac{f_t^{(m=L)} - f_t^{(m \leq L)}}{f_t^{(m=L)}}. \tag{8}$$

We also define the marginal change in the value of ASI, $\triangle V_{ASI}$. With this we measure the extra benefit gained by decreasing the number of uncertain pipeline orders by obtaining ASI sooner, from m to $m - 1$:

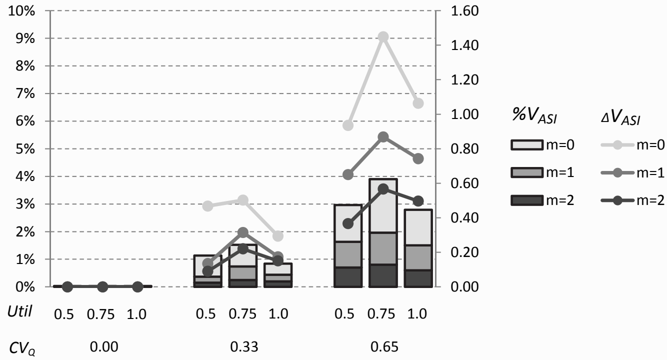
$$\triangle V_{ASI}(m-1) = f_t^{(m)} - f_t^{(m-1)}$$

Figure 3: The relative and the absolute value of ACI for $CV_D = 0$.



We present the results in Figures 3 and 4. The interplay of system parameters is relatively complex, which is exhibited in the fact that the value of ASI changes in a non-monotone manner. This holds in the case of changing the system's utilization, where the majority of the gains are made at (in our case) moderate utilizations. Increasing capacity uncertainty is where we would anticipate that the value of ASI will be increasing and majority of the

Figure 4: The relative and the absolute value of ACI for $CV_D = 0.65$.



gains would be made. This can be observed in $\triangle V_{ASI}$ for both low and high demand uncertainty scenario, while this only partially holds for $\%V_{ASI}$. The increasing demand uncertainty decreases both the relative and the absolute value of ASI. While the relative value of ASI extends over 30%, and for most of the scenarios above 10%, it drops below 4% for all scenarios under high demand uncertainty. This is expected, as the benefits will depend on to what extent the uncertainties in the system can be resolved. In the case of low demand uncertainty, ASI lowers the prevalent supply uncertainty. While in the high demand uncertainty scenario, supply uncertainty only represents a part of the total uncertainty to be resolved, and correspondingly the value of ASI is lower under this scenario. Observe also, that under the assumption of perfect ASI, the value of ASI observed represents the upper bound on the potential benefits obtained through upstream supply visibility.

The interesting observation is made when studying the influence of the ASI parameter m. Improving the ASI visibility by decreasing m from $m = L$ in the *No information* case to $m = 0$ in the *Full information*, leads to increasing marginal returns in most of the scenarios studied. As seen on the Figures 3 and 4, this holds both in the case of relative change, as well as absolute change in the optimal costs. The only outlier is the scenario with high utilization, low demand uncertainty and high capacity uncertainty in Figure 3. While we cannot conclude that the marginal returns are always increasing with the extended ASI visibility, it is clear that the majority of the benefits are gained only when we approach *Full information* case.

6. Conclusions

In this paper, we analyze a periodic review inventory system with positive lead time and stationary stochastic demand and supply capacity. As the *No information* case of our model can be considered as a positive lead time generalization of the paper by Ciarallo et al. (1994), we also extend the scope of the model by incorporating the possibility to obtain information about the available supply capacity for the pipeline orders. ASI is revealed after the order has been placed, but before it is replenished.

We show that the optimal policy is highly complex due to the extensive system's state description, where apart from the inventory position, the stream of uncertain pipeline orders has to be monitored and adapted constantly. However, despite this complexity, we show that the optimal policy is a state-dependent base-stock policy. We show that the base-stock levels should be increased to compensate for the increased replenishment uncertainty. Despite the fact that the myopic policy does not provide a good approximation for the optimal base-stock levels (and optimal costs), we show that by inclusion of the safety factor that would compensate for the future supply capacity uncertainty, the myopic policy adequately captures the risk of shortages in pipeline orders.

Numerical calculations show that the benefits obtained through ASI can be relatively big (although also highly dependent on other system parameters), however in this case ASI should be revealed for the most of the uncertain pipeline orders as we observe the increasing returns with the increasing ASI availability.

The analysis in the future could explore different alternatives to the presented ASI model. These could go into two general directions: further simplification of the system under study, or the opposite, the study of a more realistic supply chain setting. Due to the complexity of the optimal policy, obtaining the optimal parameters is still a formidable task, thus further insights could be gained by studying simplified settings (for instance constant demand, Bernoulli distributed supply capacity, etc.). For these settings explicit expressions could be obtained that would better capture the supply uncertainty structure in the system, and lead to easier determination of the base-stock levels. On the other hand, the natural extension to the single-stage inventory models is studying the multi-tier supply chains or supply networks. While these represent additional modeling challenges, one should recognize that the single-stage models provide the basic insights and act as building blocks to analyse more complex interactions in real-life supply networks. These interactions could involve capturing the uncertain supply market conditions through the use of bayesian learning to model the supply information, incentives to stimulate the information sharing in the form of supply contracts, exploring the influence of ASI on the bullwhip effect, inventory competition and allocation problems due to limited supply availability and the resulting speculative and gaming behavior of supply chain parties in response to the disclosed supply information, etc.

Appendix

Before giving the proofs, we first provide the needed notation and the definitions, which enables us to give the proofs in a concise manner. For clarity reasons, we elect to suppress the time subscripts in certain parts of the proofs. We also assume $\alpha = 1$ for the same reason.

For the m uncertain pipeline orders in $\vec{z}_t$, we know that any particular order z_i, where $i = t-m \ldots t-1$ can either be delivered in full or only partially depending on the available supply capacity revealed through ASI. Based on this we define the vector $\vec{z}_t^{\,-}$, which represents the set of orders z_i that will not be delivered in full, $z_i > Q_i$. The vector $\vec{z}_t^{\,+}$ represents the set of orders z_i that will be fully replenished, $z_i \leq Q_i$. Thus, $\vec{z}_t^{\,-} \cap \vec{z}_t^{\,+} = \vec{z}_t$ and $\vec{z}_t^{\,-} \cup \vec{z}_t^{\,+} = \varnothing$ holds. As it will be useful in some of the following derivations to include also the order z_t into the two vectors $\vec{z}_t^{\,-}$ and $\vec{z}_t^{\,+}$, we also define the extended vectors $\vec{Z}_t^{\,-}$ and $\vec{Z}_t^{\,+}$. The two corresponding supply capacity vectors are denoted as $\vec{Q}_t^{\,-}$ and $\vec{Q}_t^{\,+}$.

We denote the cumulative distribution function of the demand with $G(D_t)$, and the corresponding probability density function with $g(D_t)$, and the lead time demand counterparts with $G_t^L(D_t^L)$ and $g_t^L(D_t^L)$. The cumulative distribution function and the probability density function of supply capacity Q_t are denoted as $R_t(Q_t)$ and $r_t(Q_t)$. We assume that all the distributions are stationary.

In the following lemma, we provide the convexity results and the optimal solution to a single period cost function $C_t(y_t, \vec{z}_t, z_t)$.

Lemma 2 *Let $\hat{y}_t^M$ be the smallest minimizer of $C_t(y_t, \vec{z}_t, z_t)$ to which the optimal order $\hat{z}_t^M$ is placed, where $\hat{z}_t^M = \hat{y}_t^M - x_t$:*

1. *$C_t(y_t, \vec{z}_t, z_t)$ is convex in y_t.*

2. *$C_t(y_t, \vec{z}_t, z_t)$ is quasiconvex in z_t.*

3. *$\hat{y}_t^M(\vec{z}_t)$ is the state-dependent optimal myopic base-stock level.*

Proof: $C(y,\vec{z},z)$ is expressed in the following way:

$$C(y,\vec{z},z) = b\int_0^{\vec{Z}^-}\int_{\vec{Z}^+}^{\infty}\int_{y-\sum(\vec{Z}^- - \vec{Q}^-)}^{\infty}\left(D^L - y + \sum(\vec{Z}^- - \vec{Q}^-)\right) r(\vec{Q})\mathrm{d}\vec{Q}g^L(D^L)\mathrm{d}D^L$$
$$+h\int_0^{\vec{Z}^-}\int_{\vec{Z}^+}^{\infty}\int_0^{y-\sum(\vec{Z}^- - \vec{Q}^-)}\left(y - \sum(\vec{Z}^- - \vec{Q}^-) - D^L\right) r(\vec{Q})\mathrm{d}\vec{Q}g^L(D^L)\mathrm{d}D^L. \quad (A1)$$

To prove Part 1, we derive the first partial derivative of (A1) with respect to y, where we take into account that $\prod\left((1-R(\vec{Z}^+))R(\vec{Z}^-)\right) = 1$:

$$\frac{\partial}{\partial y}C(y,\vec{z},z) = -b + (b+h)\prod(1-R(\vec{Z}^+))\int_0^{\vec{Z}^-} G^L\left(y - \sum(\vec{Z}^- - \vec{Q}^-)\right) r(\vec{Q}^-)\mathrm{d}\vec{Q}^-, \quad (A2)$$

and the second partial derivative:

$$\frac{\partial^2}{\partial y^2}C(y,\vec{z},z) = (b+h)\prod(1-R(\vec{Z}^+))\int_0^{\vec{Z}^-} g^L\left(y - \sum(\vec{Z}^- - \vec{Q}^-)\right) r(\vec{Q}^-)\mathrm{d}\vec{Q}^-. \quad (A3)$$

Since all terms in (A3) are nonnegative, Part 1 holds. It is easy to see that the convexity also holds in x.

To show Part 2, we obtain the first two partial derivatives of $C(y,\vec{z},z)$ with respect to z:

$$\frac{\partial}{\partial z}C(y,\vec{z},z) = (b+h)(1-R(z)) \left[\prod(1-R(\vec{z}^+))\int_0^{\vec{z}^-} G^L\left(y - \sum(\vec{z}^- - \vec{Q}^-)\right) r(\vec{Q}^-)\mathrm{d}\vec{Q}^- - \frac{b}{b+h}\right], \quad (A4)$$

$$\frac{\partial^2}{\partial z^2}C(y,\vec{z},z) = -r(z)(b+h)\left[\prod(1-R(\vec{z}^+))\int_0^{\vec{z}^-} G^L\left(y - \sum(\vec{z}^- - \vec{Q}^-)\right) r(\vec{Q}^-)\mathrm{d}\vec{Q}^- - \frac{b}{b+h}\right]$$
$$+ (b+h)(1-R(z))\left[\prod(1-R(\vec{z}^+))\int_0^{\vec{z}^-} g^L\left(y - \sum(\vec{z}^- - \vec{Q}^-)\right) r(\vec{Q}^-)\mathrm{d}\vec{Q}^-\right]. \quad (A5)$$

Setting (A4) to 0 proves Part 3. Observe that $\hat{y}^M(\vec{z})$ only depends on $\vec{z}$, and not on z. Intuitively this makes sense, as due to the potential shortages in replenishment of any of uncertain pipeline orders $\vec{z}$ we increase $\hat{y}^M$ accordingly. However, when placing order z, it is not rational to adjust $\hat{y}^M$ to account for the potential shortage in replenishment of z. One merely has to hope that by ordering z up to $\hat{y}^M$, the available supply capacity will be sufficient.

For $z \leq \hat{z}^M$, the bracketed part in the first term of (A5) is not positive, thus the first part is nonnegative as a whole. Since also the second term is always nonnegative, the function

$C(y, \vec{z}, z)$ is convex on the respected interval. For $z > \hat{z}^M$ this does not hold, however we see that (A4) is nonnegative, thus $C(y, \vec{z}, z)$ is nondecreasing on the respected interval, which proves Part 2. Due to this, the $C(y, \vec{z}, z)$ has a quasiconvex form, which is sufficient for $\hat{y}^M$ to be its global minimizer.

Note, that one can show that $C(y, \vec{z}, z)$ is quasiconvex in any of z_i, where $i = t - m \ldots t-1$, in the same way as presented above. The above derivation can be considered as a generalization of the derivations for the zero lead time model presented in Ciarallo et al. (1994). We have shown that the convexity properties of the single period function also holds for the positive lead time case. $\square$

Proof of Lemma 1: The proof is by induction on t. For period T it holds $J_T(y_T, \vec{z}_T, z_T) = C_T(y_T, \vec{z}_T, z_T)$, which by using the result of Lemma 2 proves the convexity of $J_T(y_T, \vec{z}_T, z_T)$ in y_T, and using (6) for T, also the convexity of $f_T(y_T, \vec{z}_T)$ in x_T.

Assuming that f_{t+1} is convex in x_{t+1}, we now want to show that this implies convexity of J_t in y_t and f_t in x_t. Using (5) we write J_t as:

$$\begin{aligned} J_t(y_t, \vec{z}_t, z_t) &= C_t(y_t, \vec{z}_t, z_t) \\ &+ \int_0^\infty \int_0^{z_{t-m}} f_{t+1}(y_t - (z_{t-m} - Q_{t-m}) - D_t, \vec{z}_{t+1}) r(Q_{t-m}) \mathrm{d}Q_{t-m} g(D_t) \mathrm{d}D_t \\ &+ (1 - R(z_{t-m})) \int_0^\infty f_{t+1}(y_t - D_t, \vec{z}_{t+1}) g(D_t) \mathrm{d}D_t. \end{aligned} \tag{A6}$$

By taking the second partial derivative of (A6) with respect to y_t we quickly see that the convexity of J_t in y_t is preserved due to the convexity of C_t in y_t coming from Lemma 2, while the the remaining two terms are convex due to the induction argument.

To show that this also implies convexity of f_t in x_t, we first take the first partial derivative of J_t with respect to z_t[1]:

$$\begin{aligned} \frac{\partial}{\partial z} J(y_t, \vec{z}_t, z_t) &= \frac{\partial}{\partial z} C(y_t, \vec{z}_t, z_t) \\ &+ \int_0^\infty \int_0^{z_{t-m}} f'_{t+1}(y_t - (z_{t-m} - Q_{t-m}) - D_t, \vec{z}_{t+1}) r(Q_{t-m}) \mathrm{d}Q_{t-m} g(D_t) \mathrm{d}D_t \\ &+ (1 - R(z_{t-m})) \int_0^\infty f'_{t+1}(y_t - D_t, \vec{z}_{t+1}) g(D_t) \mathrm{d}D_t, \end{aligned} \tag{A7}$$

Partially differentiating (6) with respect to x_t twice, using (A2) and taking into account

[1] We define the first derivative of a function $f_t(x)$ with respect to x as $f'_t(x)$.

the first-order optimality condition by setting (A7) to zero, yields the following:

$$\begin{aligned}\frac{\partial^2}{\partial x_t^2} f(x_t, \vec{z}_t) &= (b+h)\prod(1-R(\vec{Z}_t^{\,+}))\int_0^{\vec{Z}_t^{\,-}} g^L\left(x_t+\hat{z}_t-\sum(\vec{Z}_t^{\,-}-\vec{Q}_t^{\,-})\right) r(\vec{Q}_t^{\,-})\mathrm{d}\vec{Q}_t^{\,-} \\ &+ \int_0^{\infty}\int_0^{z_{t-m}} f''_{t+1}(x_t+\hat{z}_t-(z_{t-m}-Q_{t-m})-D_t, \vec{z}_{t+1}) r(Q_{t-m})\mathrm{d}Q_{t-m} g(D_t)\mathrm{d}D_t \\ &+ (1-R(z_{t-m}))\int_0^{\infty} f''_{t+1}(x_t+\hat{z}_t-D_t, \vec{z}_{t+1}) g(D_t)\mathrm{d}D_t. \qquad \text{(A8)}\end{aligned}$$

While the expression does not get simplified as in the zero lead time case, we can easily conclude that the convexity of f_t in x_t is also preserved as all the terms above are nonnegative. □

Proof of Theorem 1: The convexity results of Lemmas 1 and 2 imply the proposed optimal policy structure. □

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INTERACTION BETWEEN TOTAL COST AND FILL RATE: A CASE STUDY

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ABSTRACT: *Forecasting plays a central role in the efficient operation of a supply chain – i.e., the total costs and fill rate. As forecasts of demand are required on a regular basis for a very large number of products, the methods developed should be fast, flexible, user-friendly, and able to produce results that are reliable and easy to interpret by a manager. In this paper we show that the supply chain costs cannot be optimal if the forecasting method is treated separately from the inventory model. We analyse the performance of the joint optimization of the modified Holt-Winters forecasting method and a stock control policy and investigate the effect of different penalties for unsatisfied demand on the total cost and fill rate of the supply chain. From the results obtained with 1,428 real time series from M3-Competition we show that an essential reduction of supply chain costs and an increase of fill rate can be achieved if we use the joint model with the modified Holt-Winters method.*

Keywords: *forecasting, inventory, fill rate, Holt-Winters method, optimization, M3-Competition*

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INTRODUCTION

The management of the global supply chain and its performance appear to be possible to boost considerably by striving for forecasting accuracy and the information sharing in order to harmonize different activities in the supply chain. As a result, costs may be lowered and customer services enhanced. So, determining the best inventory control policies is heavily dependent on the following three factors: the customers' demand pattern, the lead times and the information sharing (De Sensi et al., 2008; Wadhwa et al., 2009; Jakšič and Rusjan, 2009; Escuin et al., 2017). As demand rates are changing with time due to seasonal variations, business cycle and irregular fluctuations, effectively managing the supply chain with time-varying demand is an important issue (Zhao et al., 2016). Several authors (see, e.g., Hayya et al., 2006; Tiacci and Saetta, 2009; Syntetos et al., 2010; Liao and Chang, 2010; Danese and Kalchschmidt, 2011; Acar and Gardner, 2012) have performed research on the importance of forecasting in a supply chain. Authors investigated the impact of how forecasting is conducted on forecast accuracy and operational performances (i.e. cost and delivery performances).

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Forecasts of demand are required on a regular basis for a very large number of products so that inventory levels can be planned in order to provide an acceptable level of service to customers (Hyndman et al., 2002). The developed forecasting methods should therefore be fast, flexible, user-friendly, and able to produce results that are reliable and easy to interpret by a manager. Exponential smoothing methods are a class of methods that produce forecasts, taking into account trend and seasonal effects of data (more details can be found in Gardner (2006)). These procedures are widely used as forecasting techniques in inventory management and sales forecasting. Distinguished by their simplicity, their forecasts are comparable to those of more complex statistical time series models (Makridakis and Hibon, 2000).

Although demand data result from a demand forecasting system, they are regarded as an independent input to the stock control model in most studies. Usually, they include two steps: 1. calculate forecasts (for instance, minimising the mean square error) and 2. use obtained forecasts as an input to the inventory/production model and optimise the stock control policy (minimise the total cost). Even though this weakness has been highlighted in the academic literature, little empirical work has been conducted to develop understanding of the interaction between forecasting and stock control (Ferbar Tratar 2010; Strijbosch et al. 2011; Ma et al. 2013).

Regarding the above mentioned facts we were interested if the total cost of the supply chain and fill rate are optimal if we use the best model for forecasting demand and for inventory control policy for supply chain with centralised demand information. In the first case we treat these two models separately and calculate the total costs and fill rate (for different penalties) for forecasts obtained with different methods regarding minimising MSE. In the second case we inspect the performance of the joint model, where we determine the parameters of forecasting method to minimise the total cost of the supply chain. We use 1,428 real time series from M3-Competition to evaluate the performance of the modified Holt-Winters method. We will show that forecasts interact with the inventory model and consequently result in lower inventory costs as well as higher fill rate. We do not prescribe the required fill rate but rather analyse how the joint model with the proposed modified HW method, where the inventory costs are minimised, effects the fill rate.

The remainder of the paper is organized as follows. In Section 2 we describe the classical Holt-Winters forecasting procedure, a modified Holt-Winters procedure, our model of the supply chain, and present the proposed joint model. After the description and classification of the real time series from M3-Competition (Section 3), in Section 4, a performance of the modified HW method is demonstrated and the main findings of the paper are described.

2 METHODOLOGY

2.1 The Holt-Winters forecasting procedures and a modified HW method

Exponential smoothing methods are a class of methods that produce forecasts with simple formulae, taking into account trend and seasonal effects of the data. The HW method estimates three smoothing parameters associated with level, trend and seasonal factors. We estimated smoothing and initial parameters in HW methods by minimising the mean square error (MSE).

In the multiplicative seasonal form of HW method (MHW) fundamental equations for level (L_t), trend (b_t), seasonal factors (S_t) and forecast (F_{t+m}) are (Makridakis et al. 1998):

$$L_t = \alpha\left(Y_t / S_{t-s}\right) + \left(1-\alpha\right)\left(L_{t-1} + b_{t-1}\right) \quad (1)$$

$$b_t = \beta\left(L_t - L_{t-1}\right) + \left(1-\beta\right)b_{t-1} \quad (2)$$

$$S_t = \gamma\left(Y_t / L_t\right) + \left(1-\gamma\right)S_{t-s} \quad (3)$$

$$F_{t+m} = \left(L_t + b_t m\right)S_{t-s+m} \quad (4)$$

where m is the number of forecasts ahead, s is the length of seasonality (e.g., number of months or quarters in a year) and Y_t is the observed data at time point t. There have been many suggestions regarding restricting the parameter space for smoothing parameters α , β and γ (Hyndman and Khandakar 2008). In this paper, we follow the traditional approach, requiring that all parameters lie in the interval $\left[0,1\right]$. These estimates are set to minimize the discrepancies between the in-sample one-step-ahead predictions F_{t+1} and the observed values Y_{t+1}.

Empirical study (see Bermudez et al. 2006) illustrates that the method used to designate the initial vector has very little effect on the accuracy of the predictions obtained when smoothing and the initial parameters of the forecasting method are determined to minimise the forecast error measure. So, to initialize the level, we set $L_s = \left(Y_1 + Y_2 + \cdots + Y_n\right)/s$; to initialize the trend, we use $b_s = \left(Y_{s+1} - Y_1 + Y_{s+2} - Y_2 + \cdots + Y_{2s} - Y_s\right)/s^2$; and for initial seasonal indices we calculate $S_p = Y_p / L_s, p = 1, 2, \cdots, s$.

The additive seasonal form of HW method (AHW) works with the following equations:

$$L_t = \alpha\left(Y_t - S_{t-s}\right) + \left(1-\alpha\right)\left(L_{t-1} + b_{t-1}\right) \quad (5)$$

$$b_t = \beta\left(L_t - L_{t-1}\right) + \left(1-\beta\right)b_{t-1} \quad (6)$$

$$S_t = \gamma\left(Y_t - L_t\right) + \left(1-\gamma\right)S_{t-s} \quad (7)$$

$$F_{t+m} = L_t + b_t m + S_{t-s+m} \quad (8)$$

The equation (6) is identical to equation (2). The only differences in the other equations are that the seasonal indices are now added and subtracted instead of relying on products and ratios. The initial values for level and trend are identical to those for the multiplicative method. To initialize the seasonal indices we use $S_p = Y_p - L_s, p = 1, 2, \cdots, s$.

The modified HW method (MoHW) contains the following equations (see Ferbar Tratar (2015a)):

$$L_t = \alpha Y_t - S_{t-s} + (1-\alpha)(L_{t-1} + b_{t-1}) \tag{9}$$

$$b_t = \beta(L_t - L_{t-1}) + (1-\beta) b_{t-1} \tag{10}$$

$$S_t = \gamma(Y_t - L_t) + (1-\gamma) S_{t-s} \tag{11}$$

$$F_{t+m} = L_t + b_t m + S_{t-s+m} \tag{12}$$

The only difference between the additive and modified HW method is in the equation (9). For the modified HW method in contrast to the additive HW method the smoothing parameter α occurs only at observed data Y_t and not at seasonal factor S_{t-s}. If we consider equation (9) and replace $S_t = \alpha S_t^*$, the equation (11) becomes:

$$S_t^* = \gamma^* (Y_t - L_t) + (1 - \alpha\gamma^*) S_{t-s}^*, \quad \gamma^* = \gamma / \alpha \tag{13}$$

The other equations for the MoHW now conform to the AHW format. Thus, when we minimize forecast error with respect to the smoothing parameters, the new effect is to smooth the seasonal factors by changing them less. The initial values for level, trend and seasonal indices are identical to those for the additive method.

2.2 ETS method

The analyses were carried out also in the program R (R Core Team, 2014). The function sbplx from the nonlinear optimization package nloptr (Ypma and Borchers, 2014; Johnson, 2013) was used to estimate the smoothing parameters. For each of the series we used ets function to obtain the MSE, where we set opt.crit='mse', ic='aic', bounds='usual', so that the MSE was minimized to estimate the parameters of each model. AIC was used to select the best model (the best exponential smoothing method according the minimised MSE and the number of the smoothing parameters) and the standard parameter restrictions were applied (smoothing parameters lie in the interval $[0,1]$). We use notation ETS method. It is a state space model that includes some transition equations that describe how the unobserved components or states (level, trend, seasonal) change over time. The classical decomposition method splits a time series into a trend and a seasonal component and projects them in the forecast horizon (Escuin et al., 2017).

2.3 Symmetric relative efficiency measure

The efficiency of the MoHW method was measured in terms of the mean squared error (MSE) of the in-sample one-step-ahead forecasts and compared to that of AHW and MHW methods. Because the first two complete seasons were used to initialize the methods, these observations were excluded from the reported MSE:

$$\mathrm{MSE} = \frac{1}{T-2s}\sum_{t=2s+1}^{T}\left(Y_t - F_t\right)^2 \tag{14}$$

where Y_t is the observed data and F_t the forecast at time point *t*.

To compare the MoHW method with the other method, we first find their mean squared errors $\mathrm{MSE}_{\mathrm{MoHW}}$ and $\mathrm{MSE}_{\mathrm{method}}$ as defined above. We define the symmetric relative efficiency measure as

$$\mathrm{SREM}_{\mathrm{MoHW/method}} = \begin{cases} 1-\dfrac{\mathrm{MSE}_{\mathrm{MoHW}}}{\mathrm{MSE}_{\mathrm{method}}}; & \mathrm{MSE}_{\mathrm{MoHW}} < \mathrm{MSE}_{\mathrm{method}} \\ \dfrac{\mathrm{MSE}_{\mathrm{method}}}{\mathrm{MSE}_{\mathrm{MoHW}}}-1; & \mathrm{MSE}_{\mathrm{MoHW}} \geq \mathrm{MSE}_{\mathrm{method}} \end{cases} \tag{15}$$

The value of SREM is bounded by the interval $[-1,1]$, which mitigates the possibility of an individual time series to substantially over-weigh other series in the group. This is especially important in the study, where some methods on some series give MSE close to or equal to 0. If the average of SREM values over a group of time series is positive, this indicates that the MoHW method outperforms the other method for this particular group of series. The interpretation does not depend on the number of series in the group, so SREM can easily be applied to the M3-Competition data where different disciplines (or types) have different numbers of time series.

2.4 The supply chain model and joint optimisation

Consider a single-stage supply chain (with centralized demand information) consisting of one retailer (the most downstream unit of the supply chain) and one distributor (Ferbar Tratar et al., 2009; Ferbar Tratar, 2010). The retailer holds inventory in order to meet an external demand and places inventory replenishment orders to the distributor. Orders are placed at every time period. At time *t*, the last known value of the external demand is D_{t-1}. The retailer places order Q_t to the distributor, taking into account the demand forecast for period $t+1$ (using eq. (4), (8) or (12) for $F_{(t-1)+2} = F_{t+1}$). We assume that the order placed one period ago is received (lead time is one period). After the order placement, the external demand D_t is observed and filled. At the end of each period, the inventory cost are evaluated. If the retailer has on-hand inventory, the holding cost appears. The unsatisfied demand is backlogged and causes backordering cost for the retailer. The distributor is able to supply any requested quantity. The order placed at time *t* is received at time $t+1$ and is available to the retailer to fulfil external demand D_{t+1}.

Assuming that the retailer follows an order-up-to inventory policy, the order Q_t placed by the retailer to the distributor can be expressed as $Q_t = F_{t+1} - FS_{t-1}$, where F_{t+1} is the forecasted demand for the period $t+1$ (taking into account that the last known value of the external demand is D_{t-1}) and FS_{t-1} is the final stock for the period $t-1$ (if $FS_{t-1} > 0$ the retailer has on-hand inventory, if $FS_{t-1} < 0$ the unsatisfied demand occurs). When it is $Q_t < 0$, an order is not placed. The final stock is calculated as $FS_t = IS_t - D_t$, where the initial stock IS_t is obtained as $IS_t = Q_{t-1} + FS_{t-1}$. As the distributor has information about the external demand (centralized supply chain), it places the order, which is equal to the forecasted demand (less FS_{t-1}, if $FS_{t-1} > 0$). The missing amount of products supplied from the marketplace (assuming that a perfect substitute for the product exists) causes backordering cost for the distributor.

The costs of the supply chain are the sum of the holding and the backordering costs for all links in the supply chain. We assume the backordering cost to be higher than the holding cost, which is expressed by introducing a weight, *penalty* (= backordering cost / holding cost), that is greater than 1. In our analysis, for all calculations of total costs (average costs and minimised average costs) we assume that penalty is equal to 3 or 5.

In other words, using the common notation $X^+ = \max(X, 0)$, the supply chain costs in time period *t* are expressed as (*n=2* – total number of links in the supply chain):

$$C_t = \sum_{l=1}^{n} C_t^l = \sum_{l=1}^{n} \left(\left(IS_t^l - D_t^l \right)^+ + penalty \times \left(D_t^l - IS_t^l \right)^+ \right) \qquad (16)$$

where the initial stock can be expressed with forecast and final stock as:

$$IS_t^l = \left(F_t^l - FS_{t-2}^l \right)^+ + FS_{t-1}^l \qquad (17)$$

Because the first two seasons were used to initialize the methods, the average costs (AC) are calculated as:

$$AC = \frac{1}{T-2s} \sum_{t=2s+1}^{T} C_t \qquad (18)$$

where the supply chain costs C_t in time period *t* are defined with eq. (16).

We use definition of SREM to compare the MoHW method with others methods regarding average costs. In these cases, SREM1 measures the percentage increase or decrease of the average costs:

$$\mathrm{SREM1}_{\mathrm{MoHW/method}} = \begin{cases} 1 - \dfrac{\mathrm{AC}_{\mathrm{MoHW}}}{\mathrm{AC}_{\mathrm{method}}}; & \mathrm{AC}_{\mathrm{MoHW}} < \mathrm{AC}_{\mathrm{method}} \\ \dfrac{\mathrm{AC}_{\mathrm{method}}}{\mathrm{AC}_{\mathrm{MoHW}}} - 1; & \mathrm{AC}_{\mathrm{MoHW}} \geq \mathrm{AC}_{\mathrm{method}} \end{cases} \tag{19}$$

Since forecast is usually considered as input to the model in stock control studies the average costs for forecasts obtained with different forecasting methods regarding minimising MSE were calculated and the SREM1 of MoHW with respect to the AHW, MHW and ETS were computed. After that the smoothing and initial parameters of the forecasting method in the joint model are estimated by minimising the average costs and the SREM1 of JMoHW with respect to the AHW, JAHW, MHW, JMHW and ETS were computed (where letter 'J' means usage of the joint model).

2.5 Fill rate

A fill rate is a service metric and measures the number of units filled as a percentage of the total ordered (Guijarro et al., 2012). If customer orders total 1000 units and we can only meet 900 units of that order, the fill rate is 90%. We calculated fill rate for the retailer for every period

$$FR_t = 1 - \frac{\left(D_t - IS_t\right)^+}{D_t} \tag{20}$$

and presented the average fill rate:

$$AFR = \frac{1}{T-2s} \sum_{t=2s+1}^{T} FR_t \tag{21}$$

3 DATA

The Makridakis Competitions, known in the literature as the M-Competitions, are empirical studies that have compared the performance of a large number of major time series methods using recognized experts who provide forecasts for their method of expertise (Makridakis & Hibon, 2000). The first M-Competition (1982) used 1001 time series and 15 forecasting methods. The second M2-Competition (1993) used only 29 time series. The third M3-Competition (2000) was intended to both replicate and extend the features of the first two competitions. A total of 3003 time series was used.

The real time series from the M3-Competition are still widely used for testing new and evaluating old forecasting methods and models (Gorr and Schneider 2013; Petropoulos et al. 2014). The data sets used refer mainly to business and economic time series, although the conclusions are relevant to other disciplines as well. The original time series data can be found in R package Mcomp (Hyndman et al. 2013).

We used real seasonal time series from the M3-Competition to evaluate the performance of the modified Holt-Winters method. The analyses were carried out in Solver (Microsoft Excel 2010) and the program R (R Core Team 2014). The starting values in the minimization step were set to $\alpha_0 = \beta_0 = \gamma_0 = 0.5$ and the maximum number of iterations was set to 25,000.

In our study, we analysed 1428 monthly series. They refer to six different disciplines, as shown in Table 1. First we used ets function from R package forecast (Hyndman et al. 2014; Hynmdan and Khandakar 2008) to classify the series by the form of their trend, seasonality and noise. Table 1 also shows this classification. Here 'A' stands for 'additive', 'M' for 'multiplicative', and 'N' for 'none'.

Table 1: *Classification of monthly time series from M3-Competition*

Discipline	***Number***	***Noise***	***Trend***	***Season***	***Number***
DEMOGRAPHIC	111	A	N	N	123
FINANCE	145	A	N	A	115
INDUSTRY	334	A	A	N	167
MACRO	312	A	A	A	97
MICRO	474	M	N	N	124
OTHER	52	M	N	A	95
TOTAL	1428	M	N	M	124
		M	A	N	179
		M	A	A	56
		M	A	M	99
		M	M	N	159
		M	M	M	90
				TOTAL	1428

We applied AHW, MHW and MoHW methods on each of the series independently of its discipline and ets classification. The estimated smoothing and initial parameters and in-sample MSE values were saved and the SREM of MoHW with respect to the AHW, MHW and ETS were computed.

4 RESULTS OF THE STUDY AND DISCUSSION

For each method and series, the symmetric relative efficiency measures (SREM and SREM1) of MoHW with respect to AHW, MHW and ETS were computed. Table 2 shows averages of SREM for monthly time series. We can observe that with the MoHW method the MSE can be reduced on average by more than 4% (6%) in comparison with the AHW (MHW) method. Also, the MoHW method outperforms ETS in 77% of cases, on average by almost 16%.

The MoHW method is particularly good in capturing the behavior of microeconomic time series, where the MoHW method performs better than the ETS method on average by 26%. The MoHW method substantially outperforms other methods for classes with no seasonal component (xNN, xAN and xMN), irrespective of noise. Surprisingly, the fit of the MoHW method is better even in xAA and xAM classes, where AHW and MHW methods are theoretically the correct methods. This indicates the universality of the MoHW method regarding ETS which tries to select the most appropriate method.

Since demand data is usually considered as input to the model in stock control studies, the average costs (for the time interval $t = 2s,\ldots,T$) for forecasts obtained with different forecasting methods were calculated. Table 2 also shows the averages of SREM1 (percentage of improvement of the average costs) of MoHW with respect to AHW, MHW and ETS. We can observe that averages of the SREM1 are more than 2%, 4% and 10% (for penalty = 3 and penalty = 5) with respect to AHW, MHW and ETS. Almost the same as we observe for SREM holds for SREM1. If the MoHW substantially outperforms classical methods in some classes regarding MSE, the MoHW substantially outperforms them in the same classes regarding the average costs (as in this case the costs are calculated for forecasts considered as an input to the stock control model). We can also observe that the improvement of MoHW in comparison with other methods increases as penalty increases.

Table 2: *Averages of the SREM and SREM1*

	MSE → COST	**SREM**			**SREM1**					
					penalty = 3			**penalty = 5**		
		MoHW/ AHW	MoHW/ MHW	MoHW/ ETS	MoHW/ AHW	MoHW/ MHW	MoHW/ ETS	MoHW/ AHW	MoHW/ MHW	MoHW/ ETS
Discipline	DEMOGRAPHIC	3.3%	8.3%	13.7%	2.2%	6.4%	9.0%	2.5%	6.7%	10.1%
	FINANCE	4.1%	8.7%	18.0%	2.1%	3.5%	9.8%	2.2%	3.7%	10.5%
	INDUSTRY	2.5%	7.0%	6.7%	1.7%	4.4%	6.4%	1.8%	4.4%	7.4%
	MACRO	6.4%	4.3%	8.0%	4.1%	3.2%	6.9%	4.2%	3.5%	8.0%
	MICRO	5.3%	7.2%	26.0%	3.2%	5.0%	14.9%	3.5%	5.4%	15.5%
	OTHER	1.5%	6.6%	22.7%	1.0%	5.1%	9.6%	1.2%	5.6%	11.1%

	MSE → COST	SREM			SREM1					
					penalty = 3			penalty = 5		
		MoHW/ AHW	MoHW/ MHW	MoHW/ ETS	MoHW/ AHW	MoHW/ MHW	MoHW/ ETS	MoHW/ AHW	MoHW/ MHW	MoHW/ ETS
Type	ANN	4.4%	5.3%	26.5%	1.9%	3.2%	14.3%	2.0%	3.3%	14.6%
	ANA	2.2%	7.1%	5.5%	1.5%	3.9%	6.1%	1.6%	3.9%	7.1%
	AAN	2.9%	7.1%	20.2%	1.7%	5.4%	12.4%	1.8%	5.8%	12.6%
	AAA	4.1%	6.7%	7.0%	2.0%	4.5%	5.6%	2.1%	4.8%	6.4%
	MNN	2.9%	7.8%	26.5%	1.8%	3.7%	14.4%	2.0%	4.2%	15.4%
	MNA	3.5%	8.3%	8.5%	2.2%	7.2%	6.8%	2.4%	7.4%	8.0%
	MNM	3.9%	5.2%	9.3%	3.3%	5.3%	8.3%	3.6%	5.7%	10.3%
	MAN	3.9%	6.1%	17.5%	2.2%	2.9%	10.1%	2.4%	3.1%	10.8%
	MAA	3.3%	6.2%	8.9%	1.9%	3.9%	6.5%	2.1%	4.1%	7.8%
	MAM	8.2%	5.1%	8.2%	4.6%	4.0%	6.9%	4.8%	4.5%	7.9%
	MMN	3.5%	6.6%	20.3%	2.5%	5.0%	11.9%	3.0%	5.2%	12.3%
	MMM	9.8%	7.7%	7.7%	6.5%	5.7%	5.9%	7.1%	5.9%	6.7%
	Total	**4.5%**	**6.7%**	**15.9%**	**2.7%**	**4.5%**	**10.1%**	**2.9%**	**4.7%**	**10.9%**

In Table 3 we present the results of fill rate for the models in which forecasting and an inventory model were treated separately. The ETS method on average slightly outperforms other methods. ETS outperforms AHW and MHW for demographic and microeconomic series and for series with multiplicative noise. ETS outperforms MoHW for all dicsiplines except for industry and macroeconomics series and for all types except for ANA, AAN.

From the joint optimisation of supply chain (costs) model for $1,428$ monthly series (see Table 4), we observe the following: on average JMoHW can reduce the average costs by 5.9% (7.2%) in comparison with JAHW (JMHW) for penalty = 3 and by 9.2% (11.8%) for penalty = 5. We can see that the averages of the SREM1 increase as penalty increases. The JMoHW method outperforms the JAHW and JMHW methods for all disciplines and it is particularly good for microeconomic and demographic time series. Also, the JMoHW method outperforms the other two methods for all types and it is particularly good in MNA, MAM and MMx (multiplicative noise and trend) classes.

Table 3: *Fill rate results obtained from the supply chain model with the forecasts obtained regarding minimising MSE*

	MSE → COST	FILL RATE			
		ETS	AHW	MHW	MoHW
Discipline	DEMOGRAPHIC	98.90%	98.71%	98.80%	98.47%
	FINANCE	97.54%	97.61%	97.55%	97.48%
	INDUSTRY	96.94%	96.95%	96.97%	96.96%
	MACRO	98.83%	98.89%	98.87%	98.87%
	MICRO	93.70%	93.29%	93.35%	93.00%
	OTHER	97.39%	97.47%	97.47%	97.35%
Type	ANN	94.29%	94.53%	94.37%	94.12%
	ANA	96.31%	96.49%	96.51%	96.38%
	AAN	98.09%	98.28%	98.19%	98.24%
	AAA	98.03%	98.08%	98.05%	98.00%
	MNN	94.50%	94.33%	94.32%	94.17%
	MNA	96.54%	96.51%	96.26%	96.14%
	MNM	94.77%	93.60%	94.15%	93.48%
	MAN	97.53%	97.58%	97.58%	97.36%
	MAA	97.49%	97.48%	97.52%	97.48%
	MAM	96.84%	96.51%	96.61%	96.46%
	MMN	96.56%	96.52%	96.35%	96.43%
	MMM	97.22%	96.44%	96.90%	96.65%
	Total	**96.50%**	**96.38%**	**96.40%**	**96.25%**

Table 4: *Averages of the SREM1 obtained with the joint optimisation*

	JOINT	SREM1			
		penalty = 3		penalty = 5	
		JMOHW/ JAHW	JMOHW/ JMHW	JMOHW/ JAHW	JMOHW/ JMHW
Discipline	DEMOGRAPHIC	**7.0%**	**8.9%**	**12.5%**	**16.1%**
	FINANCE	4.0%	6.8%	7.1%	11.6%
	INDUSTRY	2.9%	5.1%	4.7%	7.1%
	MACRO	6.3%	5.5%	8.9%	8.3%
	MICRO	**7.8%**	**9.5%**	**12.6%**	**16.9%**
	OTHER	7.8%	7.3%	10.0%	11.1%

	JOINT	SREM1			
		penalty = 3		penalty = 5	
		JMOHW/ JAHW	JMOHW/ JMHW	JMOHW/ JAHW	JMOHW/ JMHW
Type	ANN	5.8%	6.6%	7.2%	10.6%
	ANA	3.1%	4.9%	5.2%	7.1%
	AAN	5.7%	6.6%	9.1%	10.6%
	AAA	5.4%	6.7%	8.9%	11.8%
	MNN	5.3%	7.3%	8.0%	11.7%
	MNA	**5.3%**	**10.0%**	**8.8%**	**15.6%**
	MNM	4.7%	8.3%	8.5%	12.3%
	MAN	4.3%	5.6%	6.9%	7.9%
	MAA	6.1%	6.5%	9.9%	9.7%
	MAM	**8.5%**	**8.7%**	**12.0%**	**14.9%**
	MMN	**7.1%**	**8.7%**	**13.1%**	**14.8%**
	MMM	**8.6%**	**8.4%**	**12.5%**	**16.6%**
	Total	**5.9%**	**7.2%**	**9.2%**	**11.8%**

In Table 5 we present the results of fill rate for the joint model. Fill rate increases as penalty increases. The MoHW methods outperforms all other methods for all types and all disciplines, except AHW for demographic time series (penalty = 3) and MHW for other time series (penalty = 5). The fill rate of the MoHW method reaches the highest value for macroeconomics time series and for AAN type series.

If we compare these results with those in Table 3, we can observe that the use of the joint model increases the fill rate of the MoHW method in comparison with the earlier superior ETS method by more than 2.5 percentage points.

The result for SREM and SREM1 (Table 2) confirms that the ETS (AHW, MHW) method more tends to over or under forecasts than the MoHW method. If we consider also the result for fill rate (Table 3), we can see that on average the ETS method gives more "positive inventory", so the ETS method over forecasts in comparison with the MoHW method. When the joint model is applied (Table 5), the MoHW method increases forecasts and higher orders are placed. Consequently, the fill rate of the MoHW method increases.

So, if the joint model is used the adapted forecasts cause more efficient ordering which provides the appropriate order-up-to level and consequently lowers the total costs and improves the fill rate.

Table 5: *Fill rate results obtained with the joint optimisation*

	JOINT	FILL RATE					
		penalty = 3			**penalty = 5**		
		AHW	MHW	MoHW	AHW	MHW	MoHW
Discipline	DEMOGRAPHIC	***99.37%***	99.22%	99.34%	99.52%	99.32%	99.61%
	FINANCE	99.10%	98.91%	99.23%	99.43%	99.31%	99.55%
	INDUSTRY	98.84%	98.77%	98.93%	99.36%	99.31%	99.44%
	MACRO	99.53%	99.46%	**99.64%**	99.71%	99.66%	**99.80%**
	MICRO	98.12%	97.71%	98.62%	98.83%	98.45%	99.43%
	OTHER	99.12%	99.19%	99.22%	99.58%	***99.71%***	99.68%
	JOINT	**FILL RATE**					
		penalty = 3			**penalty = 5**		
		AHW	MHW	MoHW	AHW	MHW	MoHW
Type	ANN	98.74%	98.22%	98.75%	99.30%	98.93%	99.56%
	ANA	98.83%	98.81%	98.88%	99.40%	99.39%	99.48%
	AAN	99.56%	99.27%	**99.63%**	99.70%	99.49%	**99.84%**
	AAA	99.23%	99.15%	99.38%	99.51%	99.46%	99.68%
	MNN	98.50%	98.06%	98.81%	99.16%	98.95%	99.49%
	MNA	98.76%	98.45%	98.99%	99.23%	98.82%	99.50%
	MNM	97.82%	97.49%	98.20%	98.75%	98.45%	99.05%
	MAN	99.34%	99.09%	99.36%	99.57%	99.44%	99.66%
	MAA	99.05%	99.07%	99.27%	99.44%	99.51%	99.64%
	MAM	98.47%	98.55%	98.85%	99.02%	98.99%	99.39%
	MMN	98.93%	98.85%	99.23%	99.29%	99.11%	99.67%
	MMM	98.20%	98.30%	99.01%	98.72%	98.70%	99.45%
	Total	**98.83%**	**98.63%**	**99.05%**	**99.29%**	**99.12%**	**99.55%**

Finally, if we use joint optimisation with the MoHW method (JMoHW) instead of the models where forecasts are calculated with the AHW, MHW or ETS method regarding minimising MSE, we can observe the following (see Table 6): on average JMoHW can reduce the average costs by more than 24% (23% and 28%) in comparison with the AHW (MHW and ETS) method for penalty = 3 and by more than 41% (40% and 43%) for penalty = 5.

The averages of the SREM1 within different disciplines vary between 18.9% and 33.1% for penalty = 3 and between 33.5% and 48.9% for penalty = 5. The JMoHW substantially outperforms other methods for microeconomic time series. The averages of the SREM1 within different classes vary between 18.3% and 36.2% for penalty = 3 and between 35.5% and 51.9% for penalty = 5. Also, the JMoHW method substantially outperforms the classical methods if a time series does not have a trend and a seasonal component. For these two classes, ANN and MNN, the averages of the SREM1 vary between 25.9% and 36.2% for penalty = 3 and between 44.3% and 51.9% for penalty = 5.

Table 6: *Averages of the SREM1 (comparison of the joint model with the MoHW method and models in which forecasting and an inventory model were treated separately)*

	JOINT/MSE	SREM1					
		penalty = 3			penalty = 5		
		JMOHW/ AHW	JMOHW/ MHW	JMOHW/ ETS	JMOHW/ AHW	JMOHW/ MHW	JMOHW/ ETS
Discipline	DEMOGRAPHIC	18.9%	19.0%	22.6%	33.5%	33.7%	36.7%
	FINANCE	21.5%	20.8%	27.0%	36.8%	36.6%	41.6%
	INDUSTRY	23.1%	23.2%	24.8%	39.6%	39.7%	41.1%
	MACRO	23.1%	22.3%	26.1%	39.2%	38.6%	42.1%
	MICRO	**27.2%**	**25.9%**	**33.1%**	**46.2%**	**45.3%**	**48.9%**
	OTHER	27.7%	28.6%	31.7%	46.2%	46.9%	48.3%
Type	ANN	**27.3%**	**27.1%**	**36.2%**	**45.7%**	**45.7%**	**51.9%**
	ANA	23.9%	24.5%	26.9%	41.0%	41.4%	43.5%
	AAN	20.1%	21.8%	27.9%	35.5%	37.1%	42.0%
	AAA	23.1%	23.4%	24.8%	40.7%	41.1%	42.2%
	MNN	**27.1%**	**25.9%**	**35.2%**	**45.2%**	**44.3%**	**50.6%**
	MNA	24.4%	26.6%	26.5%	42.3%	44.1%	42.9%
	MNM	22.6%	18.3%	21.0%	40.0%	36.7%	37.0%
	MAN	23.7%	23.1%	29.0%	40.2%	39.8%	44.4%
	MAA	23.3%	23.8%	25.3%	40.4%	40.9%	41.8%
	MAM	26.3%	23.4%	25.1%	42.8%	40.6%	41.6%
	MMN	24.6%	24.3%	30.5%	41.8%	41.7%	46.4%
	MMM	24.6%	20.6%	23.1%	40.6%	37.6%	38.7%
	Total	**24.1%**	**23.5%**	**28.1%**	**41.2%**	**40.8%**	**43.9%**

As we can see, the JMoHW method outperforms all three methods and it does not perform generally worse in any of the classes, which indicates the universality of the JMoHW method. The JMoHW method is general enough to be used as the encompassing method when the same method is applied to all time series.

5 CONCLUSION

Demand forecasting is used throughout the world more often because of proper source management and the rising need to plan. One of the most commonly used forecasting techniques is exponential smoothing, which is relatively inexpensive, fast and simple.

In this paper we presented the modified Holt-Winters method and the problem of the local optimisation of forecasting methods when the calculated forecasts are used in the inventory model. We therefore proposed the MoHW method for a simultaneous optimisation of demand forecasting and a stock control policy. The method is computationally stable, requires little storage and produces results that are easy to interpret.

This paper differs from the study of Ferbar Tratar (2015b) in adding interaction between the total cost and fill rate of the supply chain. In Ferbar Tratar (2015a), the simulation (not real data) study showed that the modified HW method can reduce the forecast error (MSE) in comparison with the other classical methods (AHW, MHW). The analysis is focused on the influence of parameters (slope, seasonality and noise) that they have on MSE obtained with the modified method. In Ferbar Tratar (2010) for the first time the problem of "the local optimisation" of the forecasting methods (AHW, MHW and improved multiplicative (not additive) HW method) was exposed. The added value to Ferbar Tratar (2010) is a case study of 1,428 real time series (and detailed inspection within different classes of discipline and type), validation of functionality of the joint model with the modified HW method and investigation into how the minimisation of the total cost influences the fill rate.

We tested the method on 1,428 real series from M3-Competition. We developed the symmetric relative efficiency measure to compare the performance of different methods. Taking averages of these measures across several time series allowed us to indicate which method is preferable in general. We showed that forecasts interact with the inventory model and consequently result in lower inventory costs as well as higher fill rates when the joint model is used. The average total costs can be reduced on average by more than 25% for penalty = 3 and by more than 41% for penalty = 5 in comparison with the models where forecasts are calculated with the AHW, MHW or ETS method regarding minimising MSE and treated separately from the inventory model. At the same time, the joint model with the MoHW method improves fill rate on average by 2.5 percentage points for penalty = 3 and by 3 percentage points for penalty = 5.

Based on the M3-Competition monthly time series we showed that the MoHW method is particularly good for microeconomic time series and for time series with multiplicative noise, trend and seasonal component. We showed that the MoHW method is general enough to be used as the encompassing method when the single method is applied to all time series.

As the method can be easily implemented in an Excel spreadsheet, we suggest that the managers and supply chain decision-makers use the JMoHW method to make better predictions and reduce costs.

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BUILDING A KNOWLEDGE ECONOMY: ARE HUNGARY'S EDUCATIONAL REFORMS THE RIGHT APPROACH?[1]

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ABSTRACT: *Technology and global connectivity are leading to accelerating dynamics of the global economy. One of the underlying driving forces is the increasing importance of immaterial resources. This has exhaustively discussed under keywords such as "knowledge economy" or the increase of "knowledge intensity". The following paper discusses the appropriateness of the youngest reforms in Hungary's higher education system against the background of a modern knowledge economy. It focuses on higher education and presents preconditions, goals and the institutional framework of a "dual approach". It briefly treats the current situation in Hungary regarding key aspects of its competitiveness and summarizes the recent policy critically.*

Keywords: *Competitiveness, Knowledge-Economy, Education Economics, Dual Studies, Vocational Education and Training*

JEL Classification: O31, E22, F66, I21, I23, I25, I28

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INTRODUCTION

In the last decades, extensive research has underscored the highly dynamic changes of the global business environment. Technology and global connectivity are leading to accelerated processes (see Dobbs et al. 2014; Werr, Greiner 2008). Immaterial resources are getting more important (Pawlowski, Edvinsson 2012, 14). Since immaterial resources have been identified as the perhaps most decisive driving force of the global economy, keywords such as "knowledge economy" (see Arvanitidis & Petrakos 2011) or the increase of "knowledge intensity" within businesses (see e.g. Smith 2002) increasingly determine the discussion of topics concerning competitiveness. Putting it another way: What, if not *knowledge* could be make firms, nations or regions more competitive? Advantages in knowledge are undoubtedly the key factor of competition. For the situation today it is determinative, that competing companies, and hence nations, face a never recognized pace of change. Therefore, the research concerning the problem of competitiveness focused on the role of knowledge in modern economies: "Knowledge is perhaps the most critical competitiveness factor. As countries move up the economic scale, the more they

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thrive on knowledge to ensure their prosperity and to compete in world markets."(Garelli 2006, 610).

According to this, *education* always has been a central topic of competitiveness research. Within the European Union education is – according to the principle of subsidiarity – a *national* challenge, and there are significant differences. Especially the Eastern European candidate countries of 2004 still show a noticeable backlog regarding several economic indexes. Provided that the global economy is accelerating and provided that immaterial resources – knowledge – are increasingly important, there is a lot to do for national governments to acquire and manage the appropriate knowledge, or: to build a modern "knowledge economy". This article discusses the appropriateness of the youngest reforms in Hungary to acquire and manage the background for the development of a modern knowledge-economy. As explained later, Hungary has already achieved a respectively high knowledge intensity. The more knowledge-intensive an economy, the more important are higher qualifications. This article focuses accordingly on tertiary, especially on higher education. An assessment of the situation in Hungary seems obvious because the higher education system faces reforms which are driven actively by the industry and brought out by policy makers with explicit reference to questions of national competitiveness. The explicit ideal is the German model which promises a more appropriate development of immaterial resources by integrating training on the working place and class room teaching: the so-called "dual" approach. This article presents briefly preconditions, goals and the institutional framework for implementing a dual approach in the Hungarian higher education system.

As a first step the first section explains the theoretical basis and discusses the role of education, especially higher education related to the viewpoint of national competitiveness. With this background, the second subsection comments on the dual approach as a "magic bullet" for the problems and gives some short notes on paradigms for Hungarian policy. The second section briefly treats the recent situation in Hungary regarding key aspects of its competitiveness. The third section focuses on the current reforms in the Hungarian higher education system. After a short comment on the actual institutional background the second subsection presents the new "dual approach" in higher education. The fourth section critically summarizes the current policy referring to the basis presented in sections two and three and gives a short outlook for further considerations.

1. COMPETITIVENESS AND KNOWLEDGE. SOME REMARKS.

1.1 National Competitiveness and Global Knowledge Economy

First of all we have to draft our understanding about competitiveness regarding firms and nations explicitly. The last decades have shown a vast amount of literature regarding the topic of competitiveness (see e.g. Nijkamp & Siedschlag 2011; Mitschke 2008): "There are no agreed definitions of competitiveness and the term seems to mean different things to different people — some may stress a country's low costs or the level of its exchange rate, others a country's technological or even its growth rate" (Boltho 1996, 2). For our perspective it is important to point out that competitiveness should not to be confused with particular aspects of economic performance. It rather provides a framework "(…) how nations and enterprises manage the totality of their competencies to achieve prosperity or profit" (Garelli 2006, 607). Referring to the principle of subsidiarity and focusing on the unit of *nations* we take the holistic definition provided by Garelli (ibid., 608) as a starting point:

> "Competitiveness of nations is a field of Economic theory, which analyses the facts and policies that shape the ability of a nation to create and maintain an environment that sustains more value creation for its enterprises and more prosperity for its people."

The increasing complexity of products and markets gives us a hint of the importance of *knowledge* in modern economies in the broadest sense. The knowledge economy index (KEI) of the World Bank Institute illustrated clearly, that the higher a country's ability *to use knowledge* for economic development, the higher the economic outcome measured in GDP per capita (see World Bank 2012).[3] The structure of the KEI, which ranks the average of the performance of a country in four pillars of the "knowledge economy framework" – economic incentives and institutional regime, education and human resources, the innovation system and ICT – (see Chen & Dahlmann 2005) is feasible. The simplicity of the key argument behind it – the more the knowledge, the more the money – is impressive. Several scholars have broached the issue that knowledge is increasingly important, moreover, there is emerging a new economic structure, the knowledge economy (see Arvanitidis & Petrakos 2011, 15f.).[4]

But – regarding the claim for competitiveness – whether a country provides an environment which is beneficial for knowledge to be used in an economically reasonable sense is a different question: What exactly is the knowledge which can be the basis for value creation? And who is responsible – which knowledge should be provided by nations, which is the knowledge the firms should create? At first sight these seem to be unsolvable questions, because competition is a discovery procedure which discovers and creates *unpredictable* knowledge (Hayek). If we take in account the aspect of Garelli's definition of competitiveness that nations face the task of generating (more) *prosperity* for their people by providing an appropriate *environment* we get a hint of the task sharing between policy makers and firms. The World Competitiveness Yearbook (IMD 2015) gives a sound reference for both poles. But "there is no single 'recipe' for competitiveness" (Garelli 2006, 609). It must be emphasized here that in an economic world with open barriers nations need to develop their *respective comparative advantages*. Hence nations need to adapt wisely both to international division of labor and their internal economic, cultural and political conditions.

In this context *education policy* is a key factor in building the competitiveness of a country. But obviously it is not enough to simply put more money into the education system

3 Last data provided for 2012.

4 See e.g. Neef et al. (1998); Burton-Jones (1999); Brinkley (2006).

(see Török 2008).[5] As value creation gets more complex, prosperity is harder to create. Regarding the dynamics of the world economy, governments face the increasingly serious challenge of reshaping education systems in regard to their structure and content (see e.g. Schlotter et al. 2008; Piopiunik & Ryan 2012; Link 2012). According to the mentioned indexes this seems particularly challenging for Eastern Europe.

1.2 A "dual approach" as magic bullet?

If nations compete in providing a better environment for the use and creation of knowledge, skills or competencies of the *workforce* come into focus. Because of the increasing dynamics it seems to "surprisingly difficult, to make professional education and training fit the needs of the workplace" (OECD 2014, 56). The environment for value-creation has to adapt and if economic change accelerates it seems to be the most feasible challenge to connect the world of work and the world of education more closely (see OECD 2013, 18). In the last years a vast amount of literature documented the need for a closer relationship.[6] To complete traditional classroom situations with learning in the workplace is an arising demand, more and more economic development seems to outpace traditional education practices. Learning in the workplace provides adaption to complexity: It "…allows young people to develop 'hard' skills on modern equipment, and 'soft' skills, such as teamwork, communication and negotiation, through real-world experience." (ibid.).

Soft skills seem to be acquired more easily in workplace situations. But the technology explosion obviously causes a shift regarding the "hard skills" needed. Recent surveys reflect a clear trend towards knowledge in technical domains: "Nearly two-thirds of overall employment growth in the European Union (EU25) is forecast to be in the 'technicians and associate professionals' category (CEDEFOP, 2012, cited in OECD 2014, 11)."

In general, the German system of Vocational Education and Training (VET) is one of the most successful models in tertiary education for keeping up with the needs of the employment market (see Hyslop 2012). The "dual approach" well known from the German model of "Berufsausbildung", which combines learning in the workplace with traditional classroom education seems to be a proper solution to face the mentioned problems. Similar systems have been developed in France, Canada, Australia, Switzerland or Austria (see OECD 2014, 22; Graf 2013). According to several surveys of the OECD, the dual approach is seen to be beneficial for employers by the productive benefit through the work done by trainees (OECD 2014, 57), for employees because of a strong learning environment (ibid., 56) and for nations, because it ensures a better linkage between the labour market and demand (ibid.).

5 A claim of the latest OECD Country Note on Hungary (see OECD 2014C).

6 See e.g. Frank et al. (2007); Etzkowitz (2008); Powell, Solga (2010); McLaughlin & Mills (2011); Graf (2013); Chen & Wu (2013).

However, regarding not only the shift towards more technical and more complex tasks in every day work (see OECD 2013, 6), but also regarding the value added, a *highly* educated workforce is the key factor in a modern economy: higher knowledge intensity and higher education levels are required (see e.g. Tremblay et al 2012, 16). There is an "increasing demand for higher level technical and professional skills" (OECD 2014, 23). "Barro and Sala-i-Martin (1995) found that higher education has the largest effect on growth compared to both secondary and primary schooling" (Arvanitidis & Petrakos 2011, 18). Therefore the shape of *higher education* comes into focus. Not only because it obviously has a greater effect on the knowledge economy, but also because it is traditionally less linked to the "world of work". This seems to be a core problem. McLaughlin and Mills (2011) called it in her study the "isolation of the sectors", which is obviously applicable for the new member states.

Undoubtedly the recent economic developments question the traditional university model (see Powel & Solga 2010). Market developments outpace the subjects taught. In addition "many professional, technical and managerial jobs require only one or two years of post-secondary career preparation, and employment growth in this sector is rapid" (OECD 2014, 22; see also Veugelers & del Rey 2014). Therefore, new types of institutions within higher education arise as alternatives to traditional universities in many countries (see Tremblay et al. 2012, 19). Based on the mentioned surveys and considerations regarding the VET System and the shifts in the labour market we assume, that a structural change towards a "dual" model in higher education, similar to the basic principles of the VET-system, could make the knowledge of graduates fit better the needs of the workplace and keep up better with the challenges of the modern world economy.[7] The general claims of the OECD (2014, 58), that apprenticeship needs to be made an *essential and integrated element* of the vocational program, rather than an optional add-on, seems to be transferable for higher education. Is a "dual approach" for higher education the magic bullet to make higher education system fit the dynamics of the economy? Hungary based its structural reforms in higher education on this assumption. The following sections provide a brief overview.

2. RECENT SITUATION IN HUNGARY REGARDING COMPETITIVENESS AND EDUCATION

The following subsections present a brief overview of the situation of Hungary regarding its competitiveness and higher education system. The first subsection provides a holistic starting point and depicts the concept and ranking of the World Economic Forum as the recently most relevant approach. It highlights the role of immaterial resources as the most important starting point for reforms regarding fostering competitiveness. The second subsection shifts the focus to the respective concrete policy area and briefly highlights the challenges for the Hungarian education system.

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7 This assumption is underpinned by recent research by Graf (2013) or OECD (2014).

2.1 Competitiveness

There is a couple of different indexes of assessing economic conditions, potentials and outcomes on national or regional level (Booysen 2002; Freudenberg 2003; Sharpe 2004). Restricting the holistic approach of Garelli to its economic content, the concept and ranking of the World Economic Forum (WEF) provides the perhaps mostly renowned and accepted starting point for considerations regarding competitiveness. It also may provide a sound basis for analyzing the concrete needs of the education system for adaptation. The WEF defines competitiveness as "the set of institutions, policies, and factors that determine the level of productivity of a country" (WEF 2013, 8). Similar to the World Bank's concept of "knowledge societies", the World Economic Forum maps its view in the *Global Competitiveness Index Framework*. It is built on a 12-pillar structure, the "12 pillars of competitiveness" (ibid., 4). The twelve pillars are related to three different categories, each representing a subindex for competitiveness: The *basic requirements subindex* is composed of the pillars institutions (1), infrastructure (2), macroeconomic environment (3), as well as health and primary education (4). The *efficiency enhancers subindex* includes the pillars higher education and training (5), goods and market efficiency (6), labor market efficiency (7), financial market development (8), technological readiness (9), and market size (10). The *innovation and sophistication subindex* includes the pillars business sophistication (11) and innovation (12). Each subindex is a key indicator of different types of economies: The *Basic requirements subindex* for "factor-driven economies", the *efficiency enhancers subindex* for "efficiency-driven economies" and the "innovation and sophistication factors subindex for "innovation-driven economies". Remarkably, the pillars (4), (5) and (11) refer to the education systems. Innovation (pillar 12) is named as a key factor for knowledge-based economies explicitly. "Business sophistication" focuses on the network effects and sophisticated business practices. In turn, sophisticated business practices require a highly skilled workforce.

The following table 1 depicts the performance of Hungary in the 5th pillar of the Global Competitiveness Index, higher education and training.

Table 1: *5th pillar of the Global Competitiveness Index, higher education and training, Hungary*

	Value	Rank/144
Secondary education enrollment, gross %*	101.6	27
Tertiary education enrollment, gross %*	59.6	44
Quality of the education system	3.3	96
Quality of math and science education	4.3	60
Quality of management schools	4.3	66
Internet access in schools	5.4	35
Availability of research and training services	3.9	85
Extent of staff training	3.6	108

Source: Schwab (2014), 11, 208.

Regarding Hungary's rank its obvious, that there is a high need for improvement regarding the quality of its education system. If we consider the category of "math and science education" as an indicator for the quality of the preparation for working in knowledge-intensive areas by means high intellectual requirements, the backlog seems remarkable.

2.2 Challenges for the educational system

Table 2 depicts the 12th pillar of the Global Competitiveness Index regarding Hungary and focuses on innovation. It seems striking, that regarding the interplay of the world of work and the world of academia Hungary stays behind. As far as we assume that the quality of networks and collaboration is decisive for the emergence of an innovation system (see e.g. Cooke 2001), the isolation of these two worlds may be a main course for Hungary's significantly worse rank regarding capacity for innovation.

Table 2: *12th pillar of the Global Competitiveness Index: Innovation, Hungary*

	Value	Rank/144
Capacity for innovation	4.0	52
Quality of scientific research institutions	3.3	97
Company spending on R&D	3.2	59
University-industry collaboration in R&D	3.9	48
Gov4888rocurement of advanced tech products	3.5	68
Availability of scientists and engineers	3.6	100
PCT patents, applications/million pop.*	0.0	124

Source: Schwab (2014), 11, 208.

However, according to the recent report of the WEF, Hungary is now on the cusp to become an *innovation-driven* economy (see Schwab 2014, 11, 208). From another point of view this means that its economy has to reach a new status of knowledge-intensity. Focusing on "the ability of a nation to create and maintain an environment" (Garelli 2006, 608) and based on the assessment of the WEF this is obviously a concrete challenge for education policy. More concretely: according to the ranking of the WEF, the Hungarian higher education system obviously should move closer to the "world of work".[8] Considering that, according to the terminology of the WEF, Hungary is in the *transition stage*, its position in row 2-5 in table 1 (highlighted), and in row 1,2,4, and 6 in table 2 (highlighted) seem to be eye-catching: Hungary has a lot of homework in enhancing an appropriate workforce, particularly in knowledge-intense areas.

The results of the WEF are similar to the diagnosis of the European Competitiveness Report (2014, 33) regarding the shares of high skilled labor in the value added in global value-chains. Moreover, the European Competitiveness Report (ibid., 36) reflects the situation

8 Regarding the general debate see Teichler (2009), especially chapter 5.

from another viewpoint: it shows a perceived *mismatch* between skills and duties. Against the background of the high manufacturing share of total value added, which is according to the latest EU Competitiveness Report the fourth highest in the EU (ibid, 22)[9], the shift to knowledge-intense and especially technical domains challenges the education system.

But it seems that until now there have been less adaptions: with 4.4% of GDP public expenditure on education Hungary'e rate is one of the three lowest among OECD countries (OECD 2014C, 1). Former full OECD country reviews (latest dates from 2008) already reflected the harmful dividing line between the world of work and the world of education. This dividing line is the more harmful the higher the importance of immaterial resources gets. Because if there is a tendency towards a higher knowledge intensity in the global economy, this dividing line may cause outpacing processes and hence a skills shortage, which severely affects a nation's competitiveness. Focusing on the Hungarian VET system, learners spent relatively little time in real work situations and are often not forced to acquire knowledge regarding the latest technical developments. The current system mostly does not ensure the possibility for the learners to adapt to everyday workplace challenges and focuses on traditional classroom teaching style. This is obviously true for higher education in Hungary as well. Efforts of a closer cooperation between institutions of higher education and the industry have been primarily driven by the most important foreign investors and had come into focus of the policy makers only in recent times after an emerging skills shortage had become obvious.

According to this, Hungary faces a double challenge. On the one hand, as recent expert recommendations argue, Hungary has a demanding need to adapt its educational system to come up with the needs of a quickly developing industry and to achieve in this manner the level of an *innovation-driven* economy.

3. RECENT DEVELOPMENTS IN THE HUNGARIAN HIGHER EDUCATION SYSTEM

3.1 Background

Traditionally higher education in Hungary emphasizes theoretical skills. VET has relatively low status and many students are oriented to VET because of poor academic performance (see Kis et al. 2008, 14). Moreover, lecturers of institutions of higher education often do not have industrial, often no practical experience at all, and curricula do not match the expectations of modern industrial employers. According to this employers often claim a lack of soft skills and the ability of graduates to solve problems in teams or independently.

9 According to the Competitiveness Report 2014, manufacturing's share of total value added comes to approximately 22%. The OECD economic survey of Hungary 2014, which presents basic statistics from 2012, shows a share of the industry of 30,6% and a share of 64,7 % of the services (see OECD 2014B).

3.2 A dual approach for higher education

Recent reform processes in higher education are linked to the change of government in Hungary in 2010. At present there is no accessible research guiding or assessing the content and structure of reforms.[10] According to this our description in the following refers to the official statements of the government and the respective higher education act as the currently only reliable sources. Between 2010 and 2014 the education system was completely restructured.[11] According to this the organizational and financial responsibility for public education now belongs to the state, not to municipal or regional administration. As many other nations, Hungary shows a distinct divide in post-secondary education between vocational education and higher education.

It is the explicit aim of the Hungarian government to make education better match the needs of the labor market and to increase the attractiveness of education. One of the key aspects is the closer cooperation between educational institutions and local companies. According to this a cornerstone of the reform is the reorganization of the vocational education and training system corresponding to German standards (see Szigeti 2015b, 4f.). It is notable, that the key arguments for the reorganization of vocational education and training are used for a new, *dual* approach in higher education (see Czomba 2015), too.

The changes forced in the educational system are, first of all, answers to the industrial structure in the light of the "reindustrialization" plans of the government (Czomba 2015; see also the European Competitiveness Report 2014 for the European perspective). According to official statements of the government Hungary plans to increase the share of industrial production in GDP from recently 23 % to 30% (Czomba 2015). This means an increased need for technical degrees, which is underpinned by the results of WEF (Schwab 2014, 11, 208). Hungary seeks to achieve a significantly more adequate workforce in a short time. The improvement in skills should range to the soft skills as well (see Szigeti 2015a, 5).

3.3 Steps towards the German model

The Hungarian policy is frankly guided by German ideals and refers explicitly to the model of the Baden Württemberg Cooperative State University (DHBW) (Szigeti 2015b), a German "Fachhochschule", (originally "Berufsakademie") which applied the approach of dual studies for almost forty years and advanced to an "University of Applied Sciences" offering Bachelor and Master degree programs according to the Bologna-System (see Graf 2013).

10 Noelke & Horn (2014) provide an excellent study regarding "Social Transformation and the Transition from Vocational Education to Work in Hungary" and focus on the traditional VET-system, not on higher education. However, their statement that "existing studies neither focus on detail on the changing situation of VET graduates nor try to directly measure the role of a specific institutional mechanism, causing the outcomes of VET graduates to change" (ibid., 432) formulates a desideratum for considerations regarding the change of higher education, too. The comparative study of Vasilache et al. (2012) focuses on structure, history and financing of the higher education system and the implementation of the Bologna-Process.

11 Almost all information is accessible only in Hungarian. A good overview in German is provided through the bq-portal (2015) of the German Federal Ministry for Economic Affairs and Energy.

In general, Germany put different models of dual studies into practice and according to the fact that 16 German federal states shape their education policy independently there is a wide range of different, continuously developing forms (see BIBB 2014, 50). A sound orientation is provided by the guidelines given by the German Council of Science and Humanities (Wissenschaftsrat 2013, 9), which differentiates six different patterns or models. Of these only two are dual degree programs in a stricter sense, meaning a designed linkage regarding institutions and content:

1) *VET-integrating degree programs* ("Ausbildungsintegrierende Studiengänge") combine bachelor degree programs with VET-programs at companies. The latter are traditionally supervised by the chambers of commerce, which invigilate the exams for the VET-part and issues the certificates. Students get both a certificate for the VET-program and a university (often of applied sciences) degree. A part of the VET-program can be creditable as a part of the studies. This is mostly practiced for combinations in the field of business (e.g. Bachelor in Business Economics and the VET-based "merchant"), technology (e.g. mechatronics) or informatics.

2) *Practice-integrating degree programs* ("Praxisintegrierende Studiengänge"): This model combines degree programs with coordinated forms of apprenticeship. This requires a good fit between the contents taught "in school" and practiced at the company. Due to this, the schedule of the curriculum – semesters, examinations, free time – is differently structured than at regular universities. There are various forms of arranging the time spent at the university or at the company, e.g. alternating months there, as at the Baden Württemberg Cooperative State University (DHBW) or in Bielefeld. Students are paid during their studies by the companies and get an average salary of 869 EUR[12]. In contrast to the form of the VET-integrating degree programs dual studies students do not get a VET-certificate at the end of their studies. Students have to apply to the company first before applying at the respective institution of higher education.

The Hungarian approach is obviously oriented towards the second form, but without breaking up the traditional structure of higher education curricula and schedule.

In July 2014 the Hungarian government modified the higher education act to enable a dual approach in higher education. § 108. § 1a defines engineering, computer sciences, agricultural sciences and business or economics (or related subjects) as possible areas of dual studies. This may partly reflect the outcome of the German practice (not the legal regulation) (see BBIB 2014, 51; Wissenschaftsrat 2013, 13), but first and foremost seems to be driven by the needs of the industrial foreign investors. Indeed, the DHBW shows a wider range of subjects; in Germany traditionally VET-based programs as e.g. nurses training are little by little more academic and are hence more and more appropriate for a dual format in higher education. To exclude these subjects may be a short-shighted aspect of the Hungarian reform.

12 According to the German platfrom http://www.duales-studium.de/fuer-schueler-und-studenten/auswertung-der-gehaltsstudie (accessed October 8, 2015)

The higher education act defines dual studies to be "in step with actual practice" and is possible for both bachelor and master degree courses. Dual degree programs must be designed as full-time programs. The concrete content regarding curriculum, the terms of admission and completion, methods and evaluation of the knowledge to be acquired has to conform with a framework given by the especially created *Council for Dual Education* ("Duális Képzési Tanács"), which accredits the partner companies as well.

The Council for Dual Education is *the key institution* of the reform process and is responsible for setting standards for the dual studies' outcomes and quality. Its president is – simultaneously – the president of the society of the multinational companies located in Hungary. Two members represent the Ministry for National Economy. The remaining ten members represent the Herman Otto Institute (agricultural development), the universities of Pécs and Győr, the Budapest Business School and the Kecskemét college, the city of Kecskemét, the Petroleum Products Quality Inspection Company, the national chamber of agriculture and the German foreign investor Audi (DKT 2016). It seems debatable, if this composition reflects the needs of all stakeholders.

Based on the new higher education act the council defines the possible areas of dual education, elaborates parameters regarding quality and evaluation for all institutions, organizations and experts taking part in dual education. It qualifies the workshops of the companies and follows up the cooperation between institutions of higher education and the companies taking part in dual studies. As a part of the new higher education strategy the Hungarian government plans that students taking part in higher dual education should reach 8 % in 2020. In January 2015 the council decided to facilitate the first enrollments in dual education in September 2015.

While vocational education and training, as in the German system, mainly addresses youth unemployment, the dual approach in higher education explicitly addresses the demand of the modern manufacturers in Hungary and the political goal to develop a more knowledge-intense economy. One of the main expectations is that graduates of dual studies already have experiences which traditional graduates lack e.g.

- Specific knowledge regarding *applying* the subjects taught
- Ability to work autonomously
- Ability to work in teams
- Trained to work effectively
- Practical knowledge regarding company and working culture

The conception of dual studies is based on explicit expectations towards the economy and the society shown in table 3.[13]

13 The information of the following subsection are drawn from information given by the Hungarian Ministry of Human Capacities and recently accessible only in Hungarian.

Table 3: *Expectations of Stakeholders in Hungary*

Expectations of the *economy*	**Expectations of *society***
• The theoretical basics acquired during the semesters have to be put into practice at the partner companies immediately • Learning at the working place should provide deepening of specific competencies • Students should acquire the latest knowledge of the industry in their working places	• The student's knowledge should respond to the demands of the employers to ensure a quicker return on investment • Institutions of higher education have to match the demands of the employment market • Employment rates should improve among students with dual degrees

Source: Szigeti (2015a, 4f.).

According to this framework the *Council for Dual Education* framed responsibilities of the companies taking part in dual studies:

- Long-term commitment to the partner institutions and the concept of dual studies
- Partner companies have to ensure expert support
- The entrance examination takes place both at the institutions of higher education and at the companies, independent of each other
- During internship the partner companies provide excellent conditions
- Students draw wages based on a contract with the company

Only companies qualified by the council are allowed to take part. Regarding processes and content the *Council for Dual Education* gives concrete prescriptions. Institutions of higher education have to promote their dual degree programs in the same way as traditional programs.[14] That means that students have to apply twice: once to the institution, once to the selected company. Each academic year consists of 48 weeks of which students are supposed to spend 26 weeks at the university, 22 weeks at their company (Szigeti 2015b, 13). Regarding the fact, that according to the new regulation the curriculum of a "dual" degree course has to accord with the traditional version of the course for 90%, the "dual" version means a remarkable higher workload for students.

Dual degrees can be offered based on a collaboration contract between institutions of higher education and companies.[15] The suitability of the partner companies is generally based on an existing regulation, the general prescriptions for internships (230/2012. VIII.28. Kormányrendelet). Among other (formal) criteria the collaboration contracts define the length of the cooperation, the parameters of the entrance qualification, the modes of evaluation of the acquired knowledge, and explicitly define the role of the

14 In Hungary the enrollment process is centralized by a nationwide application platform ("Felvi.hu").

15 Statutory source: 230/2012. (VIII.28.), § 16.

companies within the curriculum and the modes of student evaluation. Institutions of higher education and companies develop curricula together, but only to a certain extent: The "traditional content" of degree programs cannot be modified – but only replaced to an extent of 10%. Generally, the training curriculum has to include 1) the deepening of theoretical knowledge relevant for the tasks at the workplace, 2) a laboratory course, 3) autonomous project work and 4) a part of skills and competence development, e.g. communication-training or project management.

3.4 Participants

In January 2015 the Hungarian *Council for Dual Education* accepted applications of 21 institutions of higher education, which submitted proposals for 30 different types of bachelor degrees. Over all 79 dual bachelor degrees got registered. According to this in September 2015, up to approximately 1000 students will be able to enroll in a dual bachelor degree course.[16] With regard to 72,000 first semester students enrolled in the winter term 2015 overall (FELVI 2015), the share of students in dual degree programs is 1.3%. This is still far below the proportions we can observe at the ideal level of the German DHBW: The DHBW is situated in the federal state of Baden-Württemberg, which has – quite similar to Hungary – approximately 10 million inhabitants.[17] Overall 62702 first semester students have been enrolled in the winter Term 2014/2015.[18] 11644 of them have been enrolled in dual study programs of the DHBW (Geilsdsdf t 2015, 20); this is a share of 18%. It seems a notable fact, that the first launch of dual programs produced a diversity of 30 programs (over all 79 dual bachelor registered degrees in Hungary).

Another striking fact is the different diversity regarding partner companies. The Hungarian institutions contracted with approximately 350 companies as external partners. According to the information given by the Hungarian government one third of the companies are big companies, two third are SMCs (Data according to Szigeti 2015a, see Fig. 1 and 2). The DHBW in Germany may be proud of 25 times more partner companies: 9000.[19]

On the level of the federal state of Baden Württemberg the distribution of students in dual degree programs according to subject is quite similar to the situation in Hungary – 43.5% technical degrees, 44.8% Business and Economics, 11.7% Social Sciences/Welfare, likewise the distribution in all of Germany. The following graph gives an overview regarding the distribution of Students according to subject in Hungary for the winter term 2014/2015 and the latest reliable data for the term of 2014 in Germany.

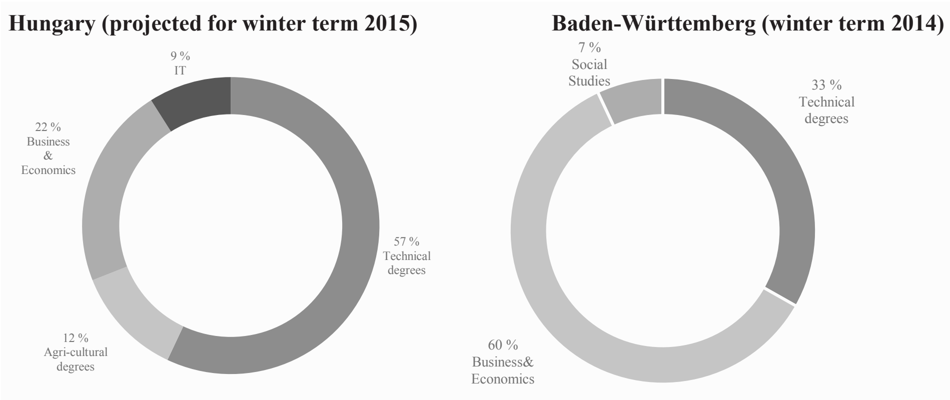
16 Regarding the actual numbers there is still no official data accessible (23.12.2015).

17 According to the latest reliable data of the statistical authority: http://www.statistik.baden-wuerttemberg.de/BevoelkGebiet/Landesdaten/bev_altersjahre.asp (accessed October 8, 2015).

18 According to the latest reliable data of the statistical authority: http://www.statistik.baden-wuerttemberg.de/BildungKultur/Landesdaten/HS_StudentenAkt.asp (accessed October 8, 2015).

19 According to the official statement of the DHBW, see http://www.dhbw.de/english/dhbw/about-us.html (accessed October 9, 2015)

Figure 1: *Distribution of students in dual degree programs according to subject in Hungary and Baden-Württemberg*

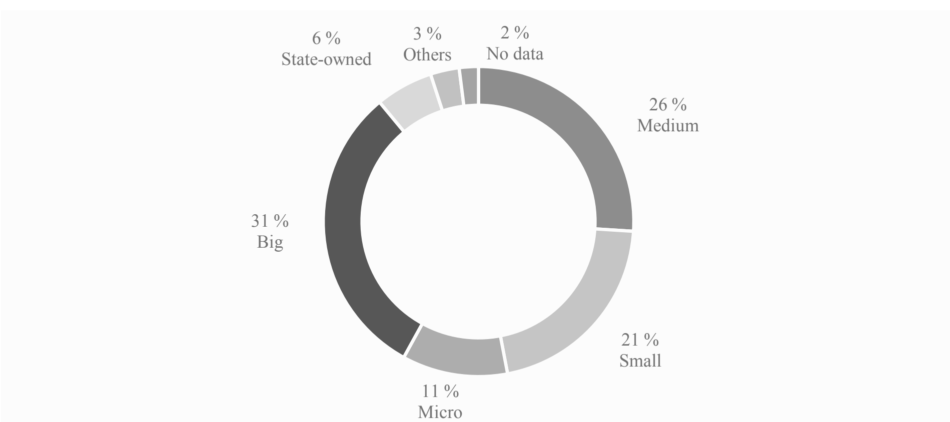


Source: Szigeti (2015b, 19), Geilsdörfer (2015, 20), own illustration.

There is a definitely similar split regarding the main groups of degrees with technical content and in business and economics. The differences between German and Hungarian economic policy is quite clearly depicted by the lack of agricultural degrees in Germany – and reversely the lack of degrees in social studies, pedagogics and health in Hungary. This distribution follows clearly the political goals of the recent government.

To incorporate more small and medium sized companies in the emerging system of dual studies the Hungarian Ministry of Human Capacities is working on a network of "dual studies centres" to give support to new partners (Szigeti 2015a, 13).

Figure 2: *Cooperating companies according to company size*



Source: Szigeti (2015b, 20), own illustration.

It seems important to note, that 12 out of 22 institutions offering dual degrees are *colleges* or, similar to the English term used in Germany "universities of applied sciences", which have traditionally a practical focus, but less of an academic reputation. 41 of the degree courses are offered by regular universities, 38 by colleges. To pick two examples: The broadest offer among the colleges is made by the Kecskemét College in the south of Hungary, with a clear technical orientation (3 engineering degrees, 1 degree in "technical management", 1 in technical IT and 1 horticultural engineering). This is obviously driven by the new production plants of German foreign investors such as Mercedes (plant founded in 2012). The University of Miskolc, an institution with a technical tradition, offers the most dual degrees among universities, but shows a broader portfolio than Kecskemét with degrees not only in technical subjects, but also in tourism, management and economics.

Overall, a specialization of the educational institutions is visible, which in each case corresponds to the regional economic structure. According to this, the involvement of companies shows an unsurprising distribution. On average, one degree course is interconnected with four companies. Degrees relating to technical subjects, first of all degrees in engineering, show a much higher participation, on average approximately double as much, partially even more.

4. FIRST CONCLUSIONS, OPEN QUESTIONS AND OUTLOOK

The "…Bologna-Process was designed to make transfer between systems or sectors more seamless for students. The emphasis to date has been on horizontal integration between universities; the creation of vertical 'seamlessness' is still only tentative" (McLaughlin & Mills 2011, 234). The statement is obviously true for Hungary. From this point of view, the current developments are pleasing. At first sight, the reforms seem to be a straight answer to the core problems we recognize when evaluating general surveys of competitiveness. The initiated form of dual studies is not a copy of the German model, but an explicit attempt to transfer its advantages to the Hungarian system. It is neither a completely new form of higher education, nor is the part of internship only a supplement. The commitment of both sides – institutions of higher education and companie are more than a simple ad-on. The idea of a central coordinating institution as the Council for Dual Education is actually expedient – though the concrete realization seems to be questionable regarding its members: why should two companies and only certain institutions of higher education have an official vote to qualify other corporate partners as suitable for dual degree programs or not? This may be only a "teething trouble" but is obviously a weak point in the institutional setting.

Based on the holistic definition of competitiveness and the results of the respective surveys we generally assess the actual reform as a first step in the right direction: Primarily in Hungary, higher education has to get less academic and closer to the world of work. The foreign direct investments of the last years – first and foremost by renowned German companies – confirm the high level of knowledge the Hungarian workforce already has. To top the existing standard of higher education with an added 22 weeks of coordinated and balanced internship – instead of introducing a completely new form of education – is perhaps less a symptom of the political unwillingness to change a system completely, but rather to raise the bar. To adopt well-tried forms of closer cooperation between institutions of higher education and companies like the German model seems to be an appropriate instrument to prove the willingness to become more than an efficiency-driven economy and to be an active and organic part of dynamic growth. Hungary still does not have a new model. Hungary has taken the first step. If the officially aimed extension of the dual degree format will be successful it will without any doubt be an evolutionary process with an increasing number of partners and a decreasing number of less traditionally designed degrees. But this has to be guided by a smart education policy and wisely developed university strategies.

The *extension* of dual studies is part of the *Council for Dual Education*'s agenda. It will be a sensitive task of educational policy to develop the now existing criteria further, namely in tune with the stakeholders of Hungarian industry. With regard to the German ideal a much higher number of partner companies should be involved in the next years – but this will apparently depend on the first experiences. Regarding e.g. the high shares of foreign investors a closer cooperation with the chambers of foreign trade would be advisable. In the long term this may change the composition and functions of the council. If the content of particular degree courses is going to change – and we can safely assume that they are going to change to an extent of more than 10 % – a closer involvement of existing players of the higher education system – as e.g. the Hungarian Accreditation Committee – would be appropriate. But as a first step, the attempt of "raising the bar" seems to be a feasible way to keep up with the increasing complexity of economic development. Of course, the created, or better, extended form of higher education provides no magic bullet to conjure up a knowledge economy. But regarding the existing structures Hungary seems to turn the right screw to make its economy more capable of developing it.

Though the institutional approach seems to need an improvement, the first participation numbers reflect that the reforms meet the needs of the stakeholders. This is clearly reflected by the regionally differing participation of partner companies and the respective portfolio of offered dual studies. Definitely, the further process of the reform will have a heavy impact on the task sharing, reputation, scientific and educational profiles as well as on the financing of colleges and universities. From this point of view, first and foremost universities will face the necessity of a greater change. To enhance the *respective comparative advantages* education policy will have to follow up closely the employability of the graduates and should measure the satisfaction of both sides carefully and nationwide. In the long term, improvements regarding Hungary's capacity for innovation, the availability of scientists and engineers, the quality of scientific research institutions (now arguably increasingly benefiting from cooperation and new possibilities for shared R&D-projects) and skill-mismatch should be recognizable. But this will take several years. Regarding the until now perceived degree of "isolation of the sectors" (McLaughlin & Mills 2011) in Hungary the briefly described means to interconnect them are promising to ensure "the ability of a nation to create and maintain an environment that sustains more value creation for its enterprises and more prosperity for its people" (Garelli 2006, 608).

For scientific reasons unfortunately, Hungary did not take part in revealing studies such as AHELO (see Tremblay et al. 2012) or PIAAC (see OECD 2013). It is hence, additionally, a scientific desideratum to follow up the measurable results of the reforms closely – for example regarding the development of skills and competences (see e.g. Shavelson 2010, Winther & Achtenhagen 2009) or the satisfaction of employers and employees (e.g. Gensch 2014). There are several unnoticed, but especially for a transformation economy highly relevant aspects such as vocational identity (see e.g. Klotz et al. 2014), or the dynamics of curriculum reforms (see Acedo 2013). Finally, integrated support of scientific and multidisciplinary monitoring would be a desirable ad-on of the process itself.

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POVZETKI V SLOVENSKEM JEZIKU

EARLY-TRANSITION OUTPUT DECLINE REVISITED

PADEC REALNEGA PROIZVODA V ZGODNJI TRANZICIJI

ČRT KOSTEVC, SAŠO POLANEC

POVZETEK: *V prispevku ponovno analiziramo padec realnega proizvoda, ki smo mu bili priča v zgodnji tranziciji iz centralno-palnskih v tržna gospodarstva. Predlagamo alternativno razlago padca proizvoda, ki je še posebej relevantna za države Srednje in Vzhodne Evrope. V ta namen v prvem delu članka razvijemo enostaven dinamičen model splošnega ravnotejža, ki bazira na delu Gomulke in Lanea (2001). Poseben poudarek je posvečen učinkom cenovne liberalizacije kot povoda za prilagoditev agregatnega proizvoda, ki je modelsko interpretirana kot odprava distorzijskih davkov. V prispevku pokažemo, da je cenovna liberalizacija v interakciji s heterogenimi stroški prilagoditve in nadomestili za brezposlenost pripeljala do padca agregatne proizvodnje hkrati pa pospešila dohodkovno neenakost. Dasiravno so te značilnosti konsistentne z dejansko gospodarsko dinamiko v državah srednje in vzhodne Evrope, pa model ne predvideva padca proizvodnje v vseh sektorjih. Namesto tega sektorji, ki so bili sprva obdavčeni celo dosežejo rast proizvoda. V drugem delu članka tako analiziramo alternativen model s samo enim sektorjem in dvema vrstama delovne sile in distorzijami na trgu delovne sile v obliki plačne kompresije v času socializma. V tem primeru je sprožilec mobilnosti delain posledičnega padca proizvoda plačna liberalizacija. Pod predpostavko heterogenosti dela glede stroškov prilagajanja in nadomestil za brezposlenost model dobro pojasnjuje padec agregatnega proizvoda vseh industrijskih panog.*

Ključne besede: *padec realnega proizvoda, liberalizacija cen, stroški prilagoditve, nadomestila za brezposelnost*

EXPLORATORY INNOVATION, EXPLOITATIVE INNOVATION AND INNOVATION PERFORMANCE: THE MODERATING ROLE OF ALLIANCE PARTNER DIVERSITY

RAZISKOVALNE INOVACIJE, UPORABNE INOVACIJE IN UČINKOVITOST INOVACIJ: VLOGA MODERIRANJA POVEZANIH RAZNOLIKIH PARTNERJEV

MLADENKA POPADIĆ, DANIJEL PUČKO, MATEJ ČERNE

POVZETEK: *Nanašajoč se na različne ugotovitve v literaturi ločimo dve različni vrsti inovacij, uporabne in raziskovalni inovacije, in preučevanje njihovih odnosov z rezultati na področju inovacij. Organizacijska ambigibljivost z zmožnostjo podjetja, da hkrati opravlja tako raziskovalne kot uporabne inovacije je bila izpostavljena kot bolj pomembna za trajnostno* *konkurenčno prednost podjetij. Z uporabo mikro podatkov o inovacijah iz 12 držav smo pokazali, da hkratno opravljane raziskovalnih in uporabnih inovacij ovira inovacijsko uspešnost podjetij. Poleg tega smo predlagali, da bi sodelovanje podjetij "z različnimi vrstami partnerjev (dobavitelji, kupci, konkurenti, raziskovalne institucije in univerze) imelo drugačen vpliv na raziskovalno in uporabno inovacijsko uspešnost podjetij. Naša raziskava je tudi pokazala, da je, sodelovanje različnih partnerjev koristno za nasprotujoče pritiske po raziskovalnih in uporabnih inovacijah.*

Ključne besede: *raziskovalne inovacije, uporabne inovacije, inovacijska uspešnost*

OPTIMAL INVENTORY CONTROL WITH ADVANCE SUPPLY INFORMATION

OPTIMIZACIJA URAVNAVANJA ZALOG Z INFORMACIJO O PRIHODNJI RAZPOLOŽLJIVOSTI OSKRBE

MARKO JAKŠIČ

POVZETEK: *Številne raziskave kažejo, da je deljenje informacij med podjetji eden ključnih pogojev za uspešno delovanje oskrbne verige. V članku preučujeva periodičen sistem uravnavanja zalog trgovca, ki je soočen s stohastičnim povpraševanjem in stohastično omejeno zmogljivostjo oskrbe s strani proizvajalca. Posledica omejene oskrbe je, da trgovec ni seznanjen z razpoložljivostjo oskrbe in da naročila praviloma niso izpolnjena v celoti. Proizvajalec je s trgovcem pripravljen deliti informacijo o prihodnji razpoložljivosti oskrbe (angl. Advance Supply Information, ASI) in s tem o dejanski velikosti dobave trgovcu. ASI postane na voljo po tem, ko trgovec odda naročilo proizvajalcu in preden je naročilo dobavljeno. Trgovec na podlagi informacije o dobavi zniža negotovost oskrbe in izboljša politiko uravnavanja zalog. Za primer uravnavanja zalog s pomočjo ASI razvijeva stohastičen model uravnavanja zalog in pokaževa, da je optimalna politika uravnavanja zalog tipa naročanja do ciljne zaloge, ki je funkcija ASI. Ker je optimalna politika relativno kompleksna, pridobiva dodatne vpoglede na podlagi analize poenostavljene miopične politike uravnavanja zalog. S pomočjo numerične analize določiva vpliv posameznih sistemskih parametrov na vrednost ASI in s tem pokaževa, da je ta močno odvisna od relativno kompleksne interakcije med parametri. Pokaževa tudi, da večino vrednosti ASI ustvarimo, ko je trgovcu na voljo skoraj popolna informacija o razpoložljivosti oskrbe.*

Ključne besede: *operacijske raziskave, zaloge, stohastični modeli, stohastična oskrba, vrednost informacij*

INTERACTION BETWEEN TOTAL COST AND FILL RATE: A CASE STUDY

INTERAKCIJA MED CELOTNIMI STROŠKI IN NIVOJEM STORITEV: ŠTUDIJA PRIMERA

LILJANA FERBAR TRATAR

POVZETEK: *Napovedovanje povpraševanja igra pomembno vlogo pri učinkovitem upravljanju dobavne verige, kot so npr. celotni stroški in nivo storitev. Ker pogosto potrebujemo napovedi za veliko število proizvodov, morajo biti uporabljene metode napovedovanja hitre, fleksibilne ter uporabniku prijazne. V članku pokažemo, da stroški dobavne verige niso optimalni, če metode napovedovanja in modele uravnavanja zalog obravnavamo ločeno. V nadaljevanju analiziramo učinkovitost optimizacije skupnega procesa napovedovanja povpraševanja in uravnavanja zalog ter raziščemo vpliv različnih penalov neizpolnjenega povpraševanja na celotne stroške in nivo storitev dobavne verige. S pomočjo rezultatov, dobljenih za 1.428 realnih časovnih vrst iz M3-Competition, pokažemo, da lahko z uporabo skupnega procesa uravnavanja zalog in napovedovanja povpraševanja z modificirano Holt-Wintersovo metodo bistveno zmanjšamo celotne stroške dobavne verige in hkrati povečamo nivo storitev.*

Ključne besede: *napovedovanje, zaloge, nivo storitev, Holt-Wintersova metoda, optimizacija, M3-Competition*

BUILDING A KNOWLEDGE ECONOMY: ARE HUNGARY'S EDUCATIONAL REFORMS THE RIGHT APPROACH?

IZGRADNJA EKONOMIJE ZNANJA: ALI JE MADŽARSKI PRISTOP K REFORMAM IZOBRAŽEVANJA USTREZEN?

JÖRG DÖTSCH

POVZETEK: *Tehnologija in globalna povezljivost vodijo v pospešeno dinamiko svetovnega gospodarstva. Ena od osnovnih gonilnih sil je večji pomen nematerialnih sredstev. To je izčrpno obravnavano v skladu s ključnimi besedami kot so "ekonomija znanja" ali povečanje "intenzivnosti znanja". Članek obravnava primernost najnovejših reform madžarskega visokega šolstva v ozadju sodobne ekonomije znanja. Osredotoča se na visokošolsko izobraževanje in predstavlja pogoje, cilje in institucionalne okvirje za "dvojni pristop". Na kratko obravnava trenutno stanje na Madžarskem na področju ključnih vidikov njene konkurenčnosti in povzema dejanske politike kritično.*

Ključne besede: *konkurenčnost, ekonomije znanja, ekonomsko izobraževanje, dvojna študija, poklicno izobraževanje in usposabljanje*