71

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Abstract

This paper analyzes productivity dynamics in Luxembourg's manufacturing sector using firm-level data for the period from 1996 to 2009. The aim is to understand the driving forces of productivity growth and derive policy suggestions to cope with the slowdown in the aggregate productivity in the aftermath of the 2007-2008 global financial crisis. The findings show that the efficiency in the allocation of production factors has an important role in shaping the time path of aggregate productivity. The long-term transformation in the production structure of the economy from steel manufacturing to financial services combined with the economic slowdown of 2001-2002 derives the inefficient producers share down in the manufacturing sector. This leads to allocative efficiency gains and a rapid growth in the aggregate productivity of the manufacturing sector. In the period after 2007, however, the allocative efficiency falls rapidly followed by negative growth in productivity, which necessitates immediate policy actions toward facilitating the reallocation of production factors.

1 Introduction

Luxembourg has the highest income per capita among the OECD countries with a robust public finance and relatively low rates of unemployment. The country constitutes an important financial center that rode out the recent economic and financial crisis so far without paying high costs. Labor and total factor productivity (TFP) indicators, however, shows that the period of rapid growth observed in the early 2000's has came to an end as the 2007-2008 international

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financial crisis hits the domestic economy (Peroni, 2012). As of 2008, productivity growth rates in Luxembourg's major sectors decrease considerably, and in 2009 negative productivity growth rates are observed together with a dramatic fall in the real GDP growth. The slowdown in the economic growth are mainly attributed to the external factors that are under the influence of the world's economic recession (e.g. OECD, 2012), but policy reforms are expected to help the economy to adopt the outside changes and sustain long term growth. As a longterm strategy to cope with financial recessions, particular importance is given to diversification in the economic activities. "The 2009 crisis led to a reduction in output and underlined the strong dependence both on the large, and potentially volatile financial sector, which accounts for one-third of GDP, and on economic conditions within the Euro area, which now faces low growth prospects. In a lower growth environment, it may be harder to sustain the current social model. Diversification notably toward high value added emerging activities remains a major challenge for the sustainability and further development of such a small economy." (OECD, 2012).

Luxembourg is a small open economy with a high degree of specialization in the production of financial services. As a matter of fact, Luxembourg has one of the lowest manufacturing sector share in the economy among the European countries (see Figure 8 in the appendix). This can be mainly attributed to the structural change in production observed in 1970's and 80's when the country's main economic activity has been transformed from steel manufacturing to financial services. The high degrees of concentration in production, however, aggravate the risks; for instance financial shocks from the outside world affect the domestic economy instantly and more intensively. Accelerating the growth in the manufacturing sector, therefore, can be considered as a strategy to alleviate the fragility of the domestic economy to the conditions in the external financial environment. In this respect, this study evaluates the growth potential of the manufacturing sector by analyzing production dynamics and detecting the driving forces of productivity growth that can be influenced by economic policy.

In the analysis of the Luxembourg's manufacturing sector, this paper utilizes firm-level data for the period from 1996 to 2009. The following section, therefore, is devoted to a descriptive analysis of manufacturing firms' production structure. The third section evaluates the evolution path of the manufacturing sector of Luxembourg. In this part, the employment growth in the total sector and in its largest industry that is the manufacturing of basic and fabricated metal products is analyzed comparatively, and a discussion is developed over firms' entry-exit dynamics. The forth section estimates a sector-level production function using alternative methods and retrieves a total factor productivity index at the firmlevel. The index is used to decompose the aggregate productivity growth to quantify the allocative efficiency and the contribution of firm entry and exit to the overall productivity performance of the sector. In the concluding section, the empirical findings are re-evaluated in the context of economic policy.

This study makes the first attempt to estimate and analyze total factor productivity at the firm-level in Luxembourg's manufacturing sector. Conducting the empirical analysis at the micro-level enables to more closely observe the production dynamics; in particular, the variation in the allocative efficiency could be computed over time and across 2-digit industries. The empirical findings show that the efficiency in the allocation of production factors has an important role in determining the aggregate productivity performance of Luxembourg's manufacturing sector. This emphasizes that sound regulation of producers' operational activities can assist to enhance productivity growth in the manufacturing sector. The results further show that the recent slowdown in the overall productivity of the economy triggered by the 2007-2008 global financial crisis necessitates urgent economic policy actions towards a more efficient allocation of production factors.

2 Overview of Dataset

The primary firm-level dataset used in this study is the Structural Business Survey (SBS) of Luxembourg that consists of nominal output and input expenditures. The output variable used in the following calculations is the nominal value of produced goods and services for a given year deflated by the 2-digit industry-level producer price index. The intermediate inputs are represented by the consumption of intermediate goods and services for a given year deflated by the intermediate input price index taken from the national accounts statistics at the 2-digit level. The labor input is the number of full and part time employees, where the number of part time employees are re-scaled based on the ratio of total annual working hours of part to full time employees. The capital stock is constructed using investment data on alternative capital assets. The investment data is deflated by the 2-digit price index for capital goods and services. The method of capital construction is described in the appendix.

The SBS contains large number of imputed data mostly for the small firms that are not obliged to report their production data regularly. The imputed data is extracted in this study, which cause loosing a large number of observations but not a large share of the market. Therefore, 85 percent of the total employment and 92 percent of all revenues in the SBS is based on actual observations and contained in the dataset used in this study, but, only 26 percent of the total number of observations remains in the sample. The final unbalanced sample based on the SBS consists of 388 firms and 3408 firm*time observations for the entire manufacturing sector for the period between 1996 and 2009. The second source of micro data is the Business Register which is used to assess information on firm demographics such as age, entry and exit status.

Table 1: Pr	oduction S	Stat. (Million	n €, #Employee)			
	Mean	Std	$\operatorname{Std}/\operatorname{Mean}$			
Capital	18.38	59.79	3.25			
Labor	90.75	225.28	2.48			
Int. Input	13.44	46.36	3.45			
Output	21.34	70.22	3.29			
Partial Correlations						
	Capital	Labor	Int. Input			
Labor	0.86	_	-			
Int. Input	0.76	0.82	-			
Output	0.79	0.86	0.97			

Table 1 displays a set of descriptive statistics on the manufacturing firms' production data. The ratio of standard deviation to mean gives the coefficient of variation that can provide insights into the degree of dispersion in data. The intermediate inputs as the most variable factor of production has the highest coefficient of variation. The coefficient of variation, however, is the lowest for the labor input mainly, because labor is not measured by working hours but the number of employees that is relatively fixed in the short term. The coefficient of variation for the capital stock also is lower than those of the intermediate inputs and output, which would make sense for a stock variable that cannot be quickly adjusted to the outside shocks.

The lower panel of Table 1 reports the partial correlation coefficients that are estimated using industry fixed effects. The intermediate inputs exhibit relatively high correlation with the output. In addition, the average ratio of the intermediate input expenditures to revenues is above 60 percent indicating that the intermediate inputs has a considerably large share in production. This is due to the organization of production in Luxembourg's manufacturing sector that heavily relies on buying and reselling of goods without adding much value to the final product. This aspect of the production method in manufacturing will be further evaluated in the next sections.

3 Evolution of Luxembourg's Manufacturing Sector

During last 40 years, the production structure of Luxembourg's economy had experienced a transformation from steel manufacturing to financial intermediation. The share of steel industry in total value added decreased from 25 percent in the early 1970's to 2 percent in 2000's, while the share of financial sector in total value added was less than 5 percent in 1970 and rose to 28 percent in 2002. During the transformation period, the share of the mining and quarry sector was reduced considerably, which also affected the evolution path of the basic and fabricated metal manufacturing industry. This is probably because the metal manufacturing industry is vertically integrated with the mining and quarry in the production chain, so that the downsizing in the mining sector raises the input prices of metal manufactures and induces the basic and fabricated metal manufacturing industry also to shrink. The contraction in the employment share of the metal manufacturing industries continues throughout the sample period, although the overall size of Luxembourg's manufacturing sector expands at the same time (see figure 1). Nevertheless during the sample period, basic and fabricated metal producing firms constitute the largest industry in the manufacturing sector with a 33 percent share in the total labor of the overall manufacturing sector, and more than 10.000 workers are employed in Luxembourg's metal manufacturing industries.



Figure 1: Employment: Total vs. Metal Manufacturing

Figure 1 displays the time paths of the total labor of manufacturing sector in comparison to the total labor employed in the metal industries. Each graph displays two lines; one for the macroeconomic indicator taken from the national accounts statistics, and one for the total employment of the firms in the sample of this study. The left panel shows that the number of employees in the overall manufacturing sector rises in the first half of the sample period until 2002 and follows a stable time path in the second half. On the right panel, however, the total labor employed in the basic and fabricated metal industries decreases considerably. In particular, the sample total of labor in metal industries dropped down rapidly after 2002.

The breaking point observed in Figure 1 coincides with the slowdown in economic activities that is known as the 2001-2002 recession of Luxembourg's economy where the GDP growth rates fell from 9 to 1 percent within the 2-year period. The effects of the crisis were felt more rapidly in the financial sector that experienced negative growth in the real gross value-added already in 2002. In manufacturing, however, the impact of the 2001-2002 recession did not occur instantly, but the recession seems to alter the long term evolution path of the sector.¹

 $^{^{1}}$ During the 2001-2002 recession, Arbed as the largest steel manufacturer in Luxembourg merged with two foreign companies Aceralia and Usinor, which formed one of the world's

In addition to the effects of 2001-2002 recession, the transformation in the production structure of Luxembourg has an important role in the size reduction of the metal manufacturing. Although a large portion of the shrinkage in the mining and quarry sector had been occurred in the early 1970's that corresponds to the first oil shock when the sector's share in total value added dropped from 25 to 12 percent in 1975, the effects of the structural transformation on the manufacturing sector seems to continue until recently. This is probably because the allocation of production factors, in particular labor, across sectors is costly and slow. A factor that causes the slow reallocation of labor can be the obligatory severance payments which are found to be excessively large in Luxembourg (e.g. OECD, 2012). The firm entry and exit rates depicted in the following parts, however, provide evidence that the 2001-2002 recession speeds up the reallocation by forcing less efficient manufacturing firms to either shrink or exit, where this phenomenon is known as the cleansing function of recessions (Caballero and Hammour, 1994). If this is the case in Luxembourg's manufacturing sector, one would expect efficiency gains in the factor allocation across manufacturing firms after 2002, which will be tested empirically in the following sections.

The entry and exit rates in the following tables and figures are calculated as the total employment ratio of entrant or exiting firms to incumbents. Incumbents are defined as the firms that operate in the current and next period. Entrants are the firms that enter into the market in the current period, while the exiting establishments are the ones that exit in the next period. The entry and exit rates are first calculated for each year and industry (or size class), and then averaged over time to reach the final statistics.

Overall Manufacturing Sector	Entry R. $(\%)$	Exit $R.(\%)$	#employees	
	0.72	2.1	29668	
Manufacturing Industries	Share in	Share in	Labor	
	Entry R. $(\%)$	Exit R. $(\%)$	Share $(\%)$	
Food, beverages and tobacco	22.7	20.1	12.3	
Textiles, leather and footwear	7.3	2.5	3.0	
Wood and cork	0.7	3.8	2.0	
Pulp, paper, print. and publish.	10.2	15.0	4.6	
Chemical, rubber, plastic, fuel	1.8	10.7	16.2	
Other non-metallic minerals	8.0	1.4	9.2	
Basic and fabricated metals	19.0	19.3	33.1	
Machinery and equipment	23.0	24.9	17.0	
Transport equipment	1.9	0.2	1.3	
Manufacturing nec; recycling	5.3	2.19	1.5	

Table 2: Annual Labor Shares, Entry and Exit Rates in Manufacturing

Table 2 shows the time-averaged annual labor-weighted entry and exit rates, and their sectoral distribution in the percentage form. The annual average entry rate is 0.72 percent in manufacturing where 23 percent of the total entry comes

largest steel producers of the time known as Arcelor.

from the machinery and equipment industry. The exit rate is 2.1 percent and 24.9 percent of the exits are also from the industry of machinery and equipment. The other two industries that contribute most to the entry and exit rates are the manufacturing of food, beverages and tobacco with 22.7 percent entry and 20.1 percent exit share, and the manufacturing of basic and fabricated metal products that constitute 19 percent of entry and 19.3 percent of exit rates in the total manufacturing sector. The basic and fabricated metal industry has the largest (33.1 percent), while the machinery and equipment has the second largest labor share (17 percent).





Figure 2 displays the total number of workers employed in entrant and exiting firms. The exiters' labor share is larger than the entrants' share in the manufacturing sector throughout the entire sample period. The employment gap between the entry and exit expands especially after 2002 that corresponds to the period of the economic slowdown in Luxembourg. The effects of the 2007-2008 global financial crisis can be observed in the last year of the sample period, where both entry and exit rates boost considerably. The future productivity gains from firm entries in 2009, however, cannot be measured by the available data, since 2009 is the last year in the sample and manufacturing firms often require a start-up period to exploit their productivity advantage and to contribute into the aggregate growth. The static allocative efficiency gains that is partially derived by the entry and exits, however, can be computed in 2009 and will be considered in the next sections.

In Figure 2, the time path of the total employment in exiting firms is more volatile than that of entrants, because exiting firms are on average larger than entrants. In the Appendix, Table 4 shows that there are 7 large firms with more than 500 employees exited the market, while only one large firm entered during the period 1996-2009. 24 middle-sized firms with more than 50 and less than 500

employees exited the market, while 12 middle-sized firms made an entry within the sample period. The descriptive statistics depicted in Figure 2 and Figure 1 shows that the employment weighted exit rates are higher than the entry rates although the total employment of the manufacturing sector is growing. This is because the incumbent manufacturing firms experience positive growth in terms of the amount of labor used in the production, which, in turn, raises the overall sector size. The contribution of entry and exit to the overall size of the sector, however, is not significantly large, since the entrant and exiting firms are small relative to incumbents.

4 Productivity and Allocative Efficiency in Luxembourg's Manufacturing

The descriptive analysis of the previous section shows that there has been a noticeable contraction in the largest manufacturing industry in Luxembourg, while the overall size of the manufacturing sector expands. Moreover, during the period from 1996 to 2009, the annual entry rates for the entire sector are on average less than 1 percent indicating that the observed growth in the total employment does not primarily stem from the entry of new producers but the individual growth performance of incumbent establishments.

The exit rates are larger in comparison to entry rates. The highest contribution to the overall exit rate, however, comes from the manufacturing industry for machinery and equipment, while the largest manufacturing industry that is for basic and fabricated metals is shrinking. The two sectors, however, are possibly integrated to each other and contain either raw or fabricated metal products within their intermediate input basket. Understanding whether the observed evolution of manufacturing sector is productivity enhancing requires taking further steps. In the below parts, firms' productivity performance will be analyzed with the aim of assessing productivity gains from the observed firm creation-destruction and the reallocation of production factors among producers. The next part is devoted to the estimation of a firm-level productivity index.

4.1 Estimation of Firm-Level Productivity

This section retrieves a firm-level TFP index through the estimation of a Cobb-Douglas type production function. The production function is in terms of three production factors, m, l and k that are intermediate inputs, labor and capital in logarithms, θ is the log of the total factor productivity (TFP) and β_i 's are the factor elasticity parameters.

$$q_{it} = \beta_0 + \beta_L l_{it} + \beta_K k_{it} + \beta_M m_{it} + \theta_{it} + \varepsilon_{it} \tag{1}$$

In the first step, the equation 1 is estimated by the OLS assuming that the error term consists of $\theta_{it} + \varepsilon_{it}$ and i.i.d. The OLS does not take into account the

endogeneity of inputs to unobserved productivity, so that the OLS estimates may be biased for the variable inputs that are expected to be positively correlated with productivity. Alternatively, this section applies two standard control function approaches in the estimation of productivity.

The Olley-Pakes (Olley and Pakes, 1996) and Levinsohn-Petrin (Levinsohn and Petrin, 2004) methods introduce the control function approach into production function estimation to take into account the endogeneity of inputs to the unobserved productivity. The Olley-Pakes proxies the unobserved component by investments and defines a probit model to control the estimation for selection. The first stage of Olley-Pakes method retrieves the elasticity parameters for labor and intermediate inputs through OLS, while in the second stage, the capital's coefficient is estimated by non-linear least squares. The Olley-Pakes estimation has a shortcoming that at the firm-level, investments may be zero for some periods which would break down the theoretical monotonic relation between productivity and the proxy. Alternatively, the Levinsohn-Petrin method utilizes intermediate inputs as a proxy for unobserved productivity and retrieves the coefficient of capital as solution to a non-linear GMM algorithm with the previous periods' inputs used as instruments. In the estimation of the production function by the two control function approaches, I also include industry and time dummies.

The two step procedure used in the Olley-Pakes and Levinsohn-Petrin methods require the implicit assumption that labor is a predetermined factor of production. Thus, the coefficient on labor input can be estimated in the first stage. The assumption on the timing of the choice of optimal labor, however, is critically reviewed by Ackerberg et al. (2006) who argues the coefficient estimate of labor would still suffer from endogeneity and be underestimated. Wooldridge's (2009) method provides a solution to the inconsistency in the identification assumption. The Wooldridge method reduces Levinsohn-Petrin estimation into a single step and abandons the predetermined labor assumption. The method estimates control function together with the production function by the GMM using a set of lagged input variables as instruments. A brief description of the three estimation methods can be found in the appendix. Table 3 displays the production function coefficient estimates by the OLS, the Olley-Pakes, the Levinsohn-Petrin and the Wooldridge methods.²

 $^{^2}$ The Olley-Pakes and Levinsohn-Petrin methods rely on nonlinear minimization routines that cause the computation variance-covariance matrix to be demanding. The standard errors, therefore, computed by block bootstrapping. In the case of the Wooldridge method, however, the computation of the covariance matrix and conducting specification tests are straightforward. In the estimation by the Wooldridge method, I apply the Kleibergen-Paap (LM) test for the underidentification and the Hansen (J) test for the overidentification. The Kleibergen-Paap LM test statistic (28.6) rejects the null hypothesis that the system is underidentified at 1% level. At 10% significance level, the Hansen J statistic (5.041) does not reject the null that overidentifying restrictions are valid. The Hansen test result, however, is not strong enough to confirm the validity of the overidentifying restrictions.

Table 3: Production Function Estimations						
	Labor	Int. Input	Capital			
OLS	0.182	0.709	0.138			
	(0.006)	(0.005)	(0.007)			
Olley-Pakes	0.180	0.709	0.159			
	(0.021)	(0.017)	(0.041)			
Levinsohn-Petrin	0.194	0.745	0.134			
	(0.017)	(0.031)	(0.043)			
Wooldridge	0.184	0.787	0.114			
	(0.025)	(0.082)	(0.041)			

Standard errors are in parenthesis.

Industry and time dummies are included.

The results of production function estimations by the four alternative methods do not yield significantly different coefficient estimates. The coefficient of labor is estimated to be around 0.2, the capital's coefficient is around 0.14 and the intermediate inputs' coefficient is around 0.7 with respect to all equations. The coefficient of intermediate inputs is particularly large in comparison to the other production factors' elasticity estimates. This is mainly because the production in Luxembourg's manufacturing sector heavily relies on buying and re-selling of goods and services. This causes the value-added to be small and the gross output to be highly correlated with firms' intermediate input consumption. The intensive usage of the intermediate inputs is possibly related to the scale of Luxembourg's manufacturing sector which restricts expanding opportunities of local producers who might otherwise produce their own intermediate inputs. High degrees of openness to international trade and being subject to intensive import penetration may also be in charge of reducing managerial incentives towards vertical integration.³

4.2 Allocative Efficiency and Decomposition of Productivity

In an industry where resources are allocated efficiently, more productive establishments accumulate a larger share of production factors. In other words, high allocative efficiency is a state of an industry where a greater portion of production factors are employed at the most efficient producers, which pushes weighted average productivity up for a given technological frontier. Recently, a large literature has emerged showing that much of the differences in income per capita among countries can be explained by the efficiency in the allocation of production factors (e.g. Banerjee and Duflo, 2005; Jeong and Townsend, 2007; Alfaro et al., 2008; Hsieh and Klenow, 2009; Bartelsman et al., 2009). Characteristics of the business environment such as the level of competition, the degree of openness to trade, the costs on entry-exit and barriers to firm development are found to be effective in determining allocative efficiency. These

 $^{^{3}}$ For details and cross-country comparisons of the import penetration and openness to trade in Luxembourg see OECD (2010) report on import penetration of goods and services.

characteristics of the business environment and the way how they impact firm dynamics are significantly related to the quality of the institutional and regulatory environment that may differ among countries as well as the industries of an economy.

This section is devoted to an analysis of the allocative efficiency in manufacturing industries of Luxembourg. The aim is to quantify the efficiency gains from the reallocation of inputs not only across continuing firms but also due to the firm entry and exit. Two different productivity decomposition approaches are employed, while the first one, the OP-Gap (Olley and Pakes,1996), is a static decomposition measuring allocative efficiency at a point in time. The second method applies a dynamic decomposition based on a study by Baily et al. (2001) and takes into account the productivity gains from entry and exit. In quantifying the allocative efficiency, three different productivity indices are used to testify the robustness of the results among alternative productivity measurement methods. The first two are labor productivity measures that are based on the ratios of deflated revenues (LP-rev) and value-added to number of employees (LP-va). The third one is the TFP index estimated by the Levinsohn-Petrin method.⁴

4.2.1 Olley and Pakes (1996) Productivity Decomposition

Olley and Pakes (1996) decompose aggregate productivity into two components that are the unweighted average productivity and the covariance term that is referred to the OP-Gap. The OP-Gap measures the static allocative efficiency in an industry at a given point in time.

$$\sum_{i}^{N} s_{it} \theta_{it} = \bar{\theta}_t + \sum_{i}^{N} \left(s_{it} - \bar{s}_t \right) \left(\theta_{it} - \bar{\theta}_t \right) \tag{2}$$

In equation 2, $\bar{\theta}_t = \sum_i^N \theta_{it}/N$ is the unweighted average productivity, s_{it} is the market share of firm in the sector, N is the total number of firms and $\bar{s}_t = 1/N$. The main concern of this section is the last term on the right hand side of equation 2, namely the OP-Gap. By calculating the covariance between the market share and productivity, one can retrieve an index to measure whether firms with larger shares in an industry are also more productive. In other words, the OP-Gap measures the static allocative efficiency for a given point in time.

In the calculation of the OP-Gap, I consider productivity in logarithms and retrieve the covariance term annually for each manufacturing sector. To create cross-industry comparisons, the annual OP-Gap is averaged over time for each 2-digit industry. In the calculation of OP-Gap with labor productivity, firms' labor shares are used as the weights, while the composite input shares, $s_{it} = m_{it}^{\beta_M} l_{it}^{\beta_L} k_{it}^{\beta_K} / \sum_{i}^{N} m_{it}^{\beta_M} l_{it}^{\beta_L} k_{it}^{\beta_K}$, are used in the TFP based OP-Gap calculations.

 $^{^4\}mathrm{Introducing}$ the other TFP indices retrieved from the OLS, Olley-Pakes and Wooldridge methods generates very similar results with the TFP estimated by the Levinsohn-Petrin method.

In a healthy functioning competitive market, one would expect production factors to be accumulated in the most productive establishments. Frictions that prevent immediate allocation of inputs across firms, may drive the OP-Gap down. These frictions can be in the form of hiring and firing costs, as well as barriers to firm entry and exit. In particular, the exit barriers such as implicit or explicit liquidation cost, taxes or mandatory payments that reduces the value of an exit decision may cause inputs to be hold by inefficient production units that would otherwise be out of the market. Firms receiving subsidy or favorable regulatory treatment may also be responsible for disrupting the market selection mechanism and worsen the efficiency in the factor allocation. Bartelsman et al. (2004) finds that the OP-Gap in transition economies is significantly lower than in Western European countries. This is attributed to the inefficiently large firms that are mostly established during the planned period and continue to operate without private incentives. Thus, the OP-Gap comparisons among economies or industries provides valuable information on the quality of the regulatory system and the degree of frictions altering firm decisions even though these institutional and regulatory factors are not directly observable in the subject industry.





Figure 3 shows that the OP-Gap based on the labor productivity that is measured by deflated revenues (LP-rev) is fluctuating around 0.25 which is roughly identical to the average OP-Gap calculated for a set of Western European economies by Bartelsman et al. (2004). The OP-Gap that is based on the value-added labor productivity is slightly lower indicating that introducing the intermediate inputs into the analysis worsens the allocative efficiency measures in Luxembourg's manufacturing industries. This is probably because some manufacturing firms with low productivity levels rely more on intermediate inputs in production and intensively engage in buying and reselling type activities without adding much value to the final product.

The OP-Gap based on the TFP is on average lower in comparison to those based on the two labor productivity indices. This indicates that introducing capital into the analysis further drives down the allocative efficiency computations. The OP-Gap based on the TFP, however, is less volatile over time. This is because when the efficiency in the usage of one factor is low, which may be due to, for instance, a negative macroeconomic shock, firms may react to such a shock by using other production factors more intensively. The overall efficiency in the use and allocation of the composite production factors, therefore, does not subject to changes as sharp as those based on a single input.

Figure 3 depicts that the OP-Gap is the highest for the period from 2002 to 2007 according to both labor and total factor productivity. In 2009, however, there is a noticeable downturn and the OP-Gap is back to the levels before 2000.



Figure 4: OP-Gap at the Industry-Level

Figure 4 provides a closer look at the OP-Gap scores of Luxembourg's industries. The labels on the vertical axis represents roughly 2-digit manufacturing industries based on NACE classification⁵, and the covariance values are on the horizontal axis. The industries are ordered according to the OP-Gap based on the LP-va. The OP-Gap calculations significantly vary among the 2-digit manufacturing industries with two industries having negative OP-Gap according to both three productivity indices. In particular, the manufacturing industry for plastics and fuel that also contains chemical and rubber manufacturing firms is the third largest manufacturing industry in terms of labor share (see Table 2) but has the lowest OP-Gap scores in terms of both the TFP and the LP-

 $^{^5\}mathrm{In}$ the classification of industries, some of the 2-digit industries are merged due to insufficient number of observations.

rev. The other two relatively large industries that are the manufacturing of food and beverages and machinery and equipment also have low allocative efficiency scores. Nevertheless, the largest industry with a 33 percent labor share that is the manufacturing of basic and fabricated metal products has relatively high OP-Gap. In particular, the OP-Gap based on the TFP is the highest in the largest industry, possibly due to the contraction in the industry size which reduces the share of inefficient producers in the market.

4.2.2 Baily et al. (2001) Productivity Decomposition (BBH)

Baily et al. (2001) decompose productivity growth into four components that are within, between, entry and exit.

$$\Delta \theta_t = \underbrace{\sum_{i \in C} \tilde{s}_i \Delta \theta_{it}}_{within} + \underbrace{\sum_{i \in C} \Delta s_i \left(\tilde{\theta}_i - \tilde{\theta}\right)}_{between} + \underbrace{\sum_{i \in E} s_{it} \left(\theta_{it} - \tilde{\theta}\right)}_{entry} - \underbrace{\sum_{i \in X} s_{it-k} \left(\theta_{it-1} - \tilde{\theta}\right)}_{exit}$$
(3)

In the above equation, $\Delta \theta_t = \theta_t - \theta_{t-k}$ is the log differenced productivity, $\theta_t = \sum_i^N s_{it} \theta_{it}$ is the weighted average of the log of productivity and $\tilde{\theta} = (\theta_t + \theta_{t-k})/2$. As before, s_{it} is firm *i*'s labor or composite input share depending on the type of the productivity index. *C*, *E* and *X* are the sets of incumbent, entrant and exiting firms respectively.

The BBH method, therefore, calculates productivity growth for a specific time interval (k years) and decomposes it into four components. The within component measures how much of the growth comes from firms' individual productivity performance. The within component is greater, if firms with larger market shares exhibit higher productivity growth. The between component computes the productivity gains due to the growth in firms' market share. The between component is larger when more productive firms exhibit higher growth in own market share.

In the BBH decomposition, both within and between components reflect allocative efficiency gains or looses. As an indicator of static allocative efficiency, the OP-Gap, for instance, can be higher, if an already large firm exhibits positive productivity growth or a high-productivity firm experiences positive market share growth holding the sector averages constant. The within component measures the former way of creating allocative efficiency gains, while the between component is the measure of the later. Lastly, the entry and exit components quantify how much of the productivity growth is generated by firm entry and exits. In this study, the BBH method is applied for every 5 year interval in the sample period and for each 2-digit industry separately. In the following discussions, the components are averaged over time or using industry weights to reach sector-level aggregates.

Figure 5 displays the time path of the 5-yearly log-differenced productivity based on the three productivity indices. The labor productivity growth is significantly higher than the TFP, especially when labor productivity is computed by the value-added. Nevertheless, both three indices follow similar paths





over time. The growth rate in 2007, which measures the growth for the period between 2002 and 2007, is the highest for the entire sample period. The rapid productivity growth period coincides with the time interval in which the OP-Gap is the highest. This shows that Luxembourg's manufacturing sector experienced an efficiency increase in the allocation of production factors which triggered high productivity growth rates for the period from 2002 to 2007.

Figure 6 shows the time averaged 5-yearly growth rates for each manufacturing industry. The industries are ordered based on their labor shares in the total manufacturing sector.

According to Figure 6, the largest manufacturing industry that is for basic and fabricated metal products exhibit relatively high productivity growth. The value-added labor productivity growth in metal manufacturing industries is, on average, more than 60 percent from a 5 year window. Combining this with the findings of the Olley-Pakes decomposition, there is some evidence that the manufacturing of basic and fabricated metal products industry constitutes the engine of productivity growth in Luxembourg's manufacturing, and the observed growth is largely sourced by the increase in the efficiency of the allocation of production factors. Figure 7 displays the components of the BBH decomposition for the four largest industries.

In Figure 7, the components of the BBH decomposition are re-scaled by their percentage share in the productivity growth rate of the 2-digit industry. Since productivity growth rates, as well as market sizes are different for each industry, direct comparison of the magnitude of the components across industries are not meaningful, but the sign of the components can be compared without loss of generality.

According to Figure 7, exiting firms contribute positively to the productivity



Figure 6: Productivity Growth at the Industry-Level

growth in the basic and fabricated metals industry. This indicates that the observed shrinkage in the metal manufacturing is productivity enhancing, namely that the market selection process clears relatively less efficient firms from the market. This is the opposite of what we observe in the food and beverages manufacturing industry where the exit component is significantly negative indicating excessive firm destruction. Nevertheless, the exit component is positive and constitute over 30 percent of the productivity growth in the manufacturing industry of machinery and equipment that is the largest contributor to the overall exit rates in Luxembourg's manufacturing.

The entry component is positive with an aggregate TFP growth contribution over 50 percent in the food and beverages manufacturing. This is somewhat expectable, since in low-tech industries the startup period of entrants are relatively short due to less sunk costs and technology intensive capital installation expenses. In more technology intensive industries, such as the other three industries in the figure, the contribution of entrants to aggregate productivity growth is visible only in the long run which possibly takes more than five years that is out of the time interval used in the decomposition exercise. Nevertheless, the contribution of firm entry to productivity growth is mostly positive in manufacturing industries indicating that the observed growth in the overall size of the manufacturing sector occurs simultaneously with the growth in productivity.

The between component in the metal manufacturing industry is slightly neg-



Figure 7: BBH Decomposition

ative indicating that the allocative efficiency is not significantly sourced by the reallocation among continuers' market shares. The within component, however, is considerably large in the basic and fabricated metal manufacturing industry. This shows that firms' individual productivity performance is an important driving force for the overall productivity growth of the sector. The large within component in metal manufacturing may also be because of the shrinkage in the industry size that leads to more intense competition which forces incumbent firms to be more productive over time. The scenario drawn for the metal manufacturing is the opposite of what is observed in the manufacturing of plastics and fuel. The productivity performances are poor and generate negative growth. The between component also is positive for the overall manufacturing sector and constitutes around 40 percent of the value-added labor productivity growth.

5 Concluding Remarks and Discussions for Economic Policy

This paper analyzes the efficiency in the allocation of production factors and productivity in the manufacturing sector of Luxembourg using a firm-level dataset for the period from 1996 to 2009. To assess the allocation and productivity dynamics in different segments of the sector, the TFP is estimated at the firmlevel, while labor productivity is computed also for each firm in the sample. The analysis of allocative efficiency provides the opportunity to monitor the interaction between productivity growth and the quality of the institutional and regulatory environment, so the empirical results obtained in this study have important policy implications. Furthermore, this paper makes the first attempt to analyze the TFP at the micro-level for Luxembourg's manufacturing, which enables to reach new findings as well as questions to be analyzed in the future research.

During the years 2001 and 2002, Luxembourg's economy experienced an economic downturn that drove the real GDP growth rates from 9 to 1 percent. The effects of the crisis were more apparent in the financial sector that experienced a rapid fall in the real gross value-added already in 2002. In manufacturing, however, the impact of the 2001-2002 recession did not occur instantly, but the recession seems to alter the evolution path of the sector. This paper provides evidence that the increase in the total employment of the manufacturing sector stopped after 2002, but the growth in productivity accelerated until 2007 mostly due to the efficiency gains in the allocation of inputs among producers. The allocative efficiency gains observed after 2002 can be interpreted as a consequence of the functioning of the cleansing mechanism of recessions. Namely, the less productive establishments suffered more from the 2001-2002 economic slowdown which in turn caused either shrink or exit of the inefficient units. More productive manufacturers exploited their productivity advantage and foster aggregate productivity growth until the end of 2007. The efficiency in the factor allocation, however, entered into a decreasing trend after 2007, and negative productivity growth rates are observed in the last two years of the sample period.

The findings of this paper show that the efficiency in the allocation of production factors has a particular importance in determining the aggregate productivity performance of Luxembourg's manufacturing sector. The importance of factor allocation is possibly due to the transformation in the production structure through which the resources are transferred from the traditional steel industry toward business services and the other segments of the economy. The indicators of productivity, however, shows that the period of rapid growth in productivity growth has come to an end by the break out of the 2007-2008 global financial crisis. The rapid fall in the efficiency of factor allocation in 2008 calls attention to a need for restructuring the policy scheme in line with the current evolution path of the manufacturing sector.

The observed loss in allocative efficiency can be recovered, for instance, by reallocating inputs from less to more productive incumbents or by enhancing firms' individual productivity performance. Improving firms' individual productivity may not be easily achieved in the short or middle term by the economic policy tools due to the stochastic nature of the innovation of new products and processes. The reallocation towards more efficient units, however, can be effectively influenced by proper institutional and regulatory design. Lowering the regulatory burden that restricts the mobility of production factors can be considered as an immediate policy action. Moreover, barriers to firms' operational activities, entry and exit may impede the reallocation of production factors and require attention while reshaping the policy agenda.

The OECD's Economics Survey (2012) overviews the factors that generate obstacles to microeconomic restructuring of Luxembourg's economy. Accordingly, the system of licensing has been found excessively complicated and costly. The existing framework of wage determination is argued to be not significantly linked with labor productivity. This may deteriorate the allocation of labor in the way that more productive workers may stay unemployed or be used inefficiently, while the available jobs are occupied permanently by less productive labor force. As a type of exit barrier, employment protection legislation is found to be excessively strict; namely that an exiting establishment has to comply with additional notice periods and high severance payments that cause the exit procedure to be burdensome and even not optimal in some cases.

The exit of inefficient units has an immediate positive as well as long term effects on aggregate productivity. The long term effects of firm exit occur by motivating potentially more efficient firms to capture the abandoned market share, which creates opportunities to grow and catch up with the international competitors. The exit of less efficient firms may have an indirect positive effect on the efficiency in the use of inputs, when the released factors of production are recombined in a more productive way in the newly created or already existing production units. Regulatory barriers that generate high costs on market entry and exit, therefore, would prevent functioning of this mechanism so that can be detrimental to allocative efficiency and the long term aggregate productivity growth.

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6 Appendix

Table 4: Size Distribution, Entry and Exit Rates in Manufacturing Sector						
Size Class	Share $(\%)$	#entrant	Entry R. $(\%)$	#exiter	Exit R. (%)	
≤ 50	13.24	69	1.16	66	1.20	
$> 50, \le 250$	28.97	9	0.67	19	1.70	
$> 250, \le 500$	21.42	3	1.03	5	1.68	
> 500	36.37	1	0.43	7	3.09	

Classification and shares are based on number of employees.

Rates are employment shares of entrants or exiters within size classes.



Figure 8: Manufacturing Sector's Share in the Economy

6.1 Construction of Firm-Level Capital Stock

This study measures the firm-level capital stock based on the perpetual inventory method (PIM). The PIM formulates the capital stock to be consist of the acquisition and obsolescence components. The acquisitions into capital stock are investments in the form of rent or purchases of capital goods and services. The obsolescence of capital, however, occurs in alternative ways such as the depreciation, retirement and sale of capital goods. The below formula combines the acquisitions of capital goods and the geometric depreciation profile, which is the simple and most commonly used form of the benchmark equation of the PIM (e.g. OECD, 2009).

$$k_{it} = (1 - \delta)k_{it-1} + I_{it}$$

$$= (1 - \delta)^{t} k_{i0} + \sum_{j=1}^{t} (1 - \delta)^{t-j} I_{ij}$$
(4)

In equation 4, two versions of the capital identity are given that are identical to each other where k, I and δ are the ex-post capital stock, investments and the rate of depreciation that is assumed to be constant over time and the same for all firms. i and t are the firm and time identifiers. The first term on the right hand-side, therefore, is a function that represents the depreciation pattern of existing capital, and the second term is acquisitions.

Equation 4 accommodates the depreciation as well as sales of capital stock that are contained in investments for which the gross fixed capital formation is used in the empirical application. The retirement of capital, however, is not represented in equation 4 and is unobservable by the available data. The retirement pattern of capital assets are modeled by assuming that the retirement probability of an asset has a Weibull distribution.

$$F_T = \alpha \lambda \left(\lambda T\right)^{\alpha - 1} e^{-(\lambda T)^{\alpha}} \tag{5}$$

Equation 5 represents the Weibull distribution where T is the time index, α and λ are the parameters of the density function. Figure 9 displays the density functions for each asset class.



Figure 9: Retirement Probabilities

Table 5 shows the parameter assumptions for the retirement profile. Every capital asset has a certain life time, so that different service life times are assigned to each asset class together with an asset specific depreciation rate which are also given in the table.

Table 5:	Parameter	Setup	for	Capital	Stock	Measurement
				-		

Asset Type	δ	life (years)	α	λ
Unconstructed Land	0.00	>14	1.2	0.01
Constructions and Arrangement of Grounds	0.02	>14	1.5	0.03
Machinery and Equipment	0.06	10	1.6	0.10
Furnitures	0.07	10	1.6	0.08
Vehicles and Other Transportations	0.09	13	3.0	0.09
Software	0.05	5	1.9	0.15
Unknown Type	0.05	>14	1.6	0.08

In Table 5, the life time of unconstructed land, constructions and the unknown type of capital are assumed to be longer than 14 years that is the span of data used in this study. The unknown type capital represents the initial capital that is roughly approximated and consists of an unknown combination of capital assets. The initial capital, therefore, is assumed to contain mostly the assets with long service lives like buildings, land and other constructions for establishing the material infrastructure.

The initial capital is approximated at the aggregate-level using a simple iterative approach (e.g. Kohli, 1982). Once the initial capital for the total sample is approximated, it is distributed among firms using firms' input shares (e.g. Martin, 2006). The method requires a proxy for long-run growth rate of investments for which I use the average annual aggregate investment growth for the sample during the period between 1996 and 2009. The equation for initial capital can be derived by expressing the aggregate capital stock as a sum of previous periods investments.

$$K_t \approx \left[I_t + (1 - \delta) I_{t-1} + (1 - \delta)^2 I_{t-2} + \cdots \right]$$
 (6)

Assuming a long-run growth rate for investments, g_{LR} , one can define the long-run investment path that is $I_t = (1 + g_{LR}) I_{t-1}$, so that the capital identity can be written as follows.

$$K_t \approx I_t \left[1 + \frac{(1-\delta)}{(1+g_{LR})} + \frac{(1-\delta)^2}{(1+g_{LR})^2} + \cdots \right]$$
 (7)

As long as $(1 - \delta) / (1 + g_{LR})$ is lower than one, one can find the value into which the stationary series converge, so that the following approximation can be defined without loss of generality.

$$K_0 \approx I_1 / \left(\delta + g_{LR}\right) \tag{8}$$

The total sum of initial capital, K_0 , is disaggregated based on firms' labor shares in the total manufacturing sector.

6.2 Estimation of Production Functions

This study employs three production function estimation routines without significantly modifying the original specifications. Below parts describe the estimation methodology.

6.2.1 Levinsohn and Petrin (2003)

Assuming a Cobb-Douglas type functional form, the value added (v_{it}) specification of the logged production function can be written as follows.

$$v_{it} = \alpha^L l_{it} + \alpha^K k_{it} + \phi \left(m_{it}, k_{it} \right) + \varepsilon_{it} \tag{A.4}$$

Therefore, l_{it} and k_{it} stand for the labor and capital inputs where m_{it} is the proxy variable that is intermediate input in the LP. In equation A.4, $\phi_{it}(\cdot) = M_{it}^{-1}(\cdot)$ is the control function in an unknown form. It is not possible to identify the coefficient of the capital input separately from the non-parametric part of the estimation $\phi(m_{it}, k_{it})$ in a single step, so that the LP requires two steps. The first step defines a non-parametric function $g(m_{it}, k_{it})$ which is represented by a 3rd order polynomial in its arguments (e.g. Levinsohn et al., 2004). The function contains the unobserved productivity and the state variable capital jointly.

Assuming l_{it} is the variable factor of production, the identification of the coefficient of the variable factor (α^L) is feasible in the first step. The first stage regression equation can be written as follows.

$$v_{it} = \alpha^L l_{it} + g\left(m_{it}, k_{it}\right) + \varepsilon_{it} \tag{A.5}$$

$$g(m_{it}, k_{it}) = \alpha^{K} k_{it} + \phi(m_{it}, k_{it})$$
(A.6)

Estimation of A.5 by OLS provides the coefficient estimate $\hat{\alpha}^L$. Additionally, we can retrieve an estimate of the function $g(m_{it}, k_{it})$ from which the unobserved productivity can be retrieved for given parameter value of α^K .

$$\hat{\theta}_{it} = g\left(m_{it}, k_{it}\right) - \alpha^{K*} k_{it} \tag{A.7}$$

Assuming the productivity to follow an unknown first order Markov process, the evaluation of firm-level productivity can be written in the polynomial specification as follows.

$$\hat{\theta}_{it} = \gamma_0 + \gamma_1 \hat{\theta}_{it-1} + \gamma_2 \hat{\theta}_{it-1}^2 + e_{it}$$
(A.8)

Accordingly, for given α^{K*} , one can run the above regression and the fitted values can be obtained as an approximation to the expectation of productivity ity conditional on previous period's productivity realization $E(\theta_{it} \mid \widehat{\theta}_{it-1}) = h(\widehat{\theta}_{it-1})$. Therefore, joint minimization of the error terms $(\varepsilon_{it} + e_{it})$ with respect to α^{K} would provide an estimate of the coefficient of capital. The equation A.9 represents the second step of the estimation routine.

$$\min_{\alpha^{K}} \left[\varepsilon_{it} + e_{it} = v_{it} - \hat{\alpha}^{L} l_{it} - X_{it} \hat{\beta} - \alpha^{K*} k_{it} - h(\hat{\theta}_{it-1}) \right]$$
(A.9)

Following the Stata code provided by Levinsohn et al. (2004), we solve the minimization problem through a non-linear least squares algorithm (Stata's *nl* command), and the standard errors are obtained by block bootstrapping.

6.2.2 Olley and Pakes (1996)

The OP approach is the starting point of the literature of production function estimations with control function and constitutes the benchmark model. Unlike the LP, OP relies on a dynamic structural model where firms hire inputs by solving a maximization problem with an objective function that consists of the sum of discounted profit streams.

The OP method employes investments (i_{it}) as the proxy variable, and the exit probabilities (\hat{P}_{it}) that are retrieved from a probit estimation are introduced into the control function, $h\left(g_{t-1}(i_{it},k_{it}),\hat{P}_{it}\right)$, as a state variable. The control function is approximated by a 2nd order polynomial in Stata codes provided by Poi et al. (2008). Therefore, assuming a Cobb-Douglas type production function in terms of output (q_{it}) , and introducing the intermediate inputs (m_{it}) as a variable factor of production, the induced form of the last stage equation can be written as follows.

$$q_{it} = \hat{\alpha}^L l_{it} + \hat{\alpha}^M m_{it} + \alpha^{K*} k_{it} + h\left(g_{t-1}, \hat{P}_{it}\right) + \varepsilon_{it} + e_{it}$$
(A.10)

$$g_t(i_{it}, k_{it}) = \hat{\phi}_t(i_{it}, k_{it}) - \alpha^{K*} k_{it}$$
(A.11)

The OP approach jointly minimizes the error terms ε_{it} and e_{it} by nonlinear least squares. As in the original OP approach, I use firm age as a control variable and the exit dummy to estimate firms' exit probabilities.

6.2.3 Wooldridge (2009)

Wooldridge's (2009) method reduces the two step estimation approach given in the OP and LP into single step. Wooldridge points out that the OP and the LP routines do not take into account the simultaneous correlation between the error terms of the equations of the two steps, and do not account for serial correlation or heteroscedasticity. Combining the two steps of the LP yields the following estimating equation.

$$y_{it} = \alpha^{K} k_{it} + \alpha^{L} l_{it} + g \left[\sum_{j=0}^{J} \sum_{z=0}^{J-j} \gamma_{j,z} m_{it-1}^{J} k_{it-1}^{z} \right] + \varepsilon_{it} + e_{it}$$
(A.12)

In the empirical application, the function $g(\cdot)$ is further assumed to be in the form of a second order polynomial. The instrument matrix therefore consist of k_{it} , l_{it-1} and f_{it-1} where f represents all terms of the polynomial that is in terms of m and k.