Charles University

Faculty of Social Sciences
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MASTER'S THESIS

The Role of Income Tax Progressivity in GDP Smoothening: Empirical Analysis

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently; using only the listed resources and literature, and the thesis has not been used to obtain a different or the same degree.

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Prague, May 12, 2017

Signature

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I am thankful to the supervisor for being patient and letting me work on my own with no pressure from his side. I would also like to express my gratitude to my parents, girlfriend, other good friends, brother, and to the rest of the family for their support during my studies and especially when I was writing this thesis.

Abstract

This thesis studies the relationship of income tax progressivity and output volatility. Using our dataset of 31 OECD countries and Bayesian model averaging (BMA) approach to address the model uncertainty issue, we find positive evidence that higher income tax progressivity leads to lower output volatility. This effect is robust to different prior specifications in BMA and to different tax progressivity measures, including our newly constructed measure which is based on the slope of the average tax curve. We also find a strong effect of tax progressivity on the consumption volatility and the volatility of hours worked which we see as the main channels for the reducing effect of tax progressivity on output volatility.

JEL Classification	E21, E32, F44, H24
Keywords	tax progressivity, GDP volatility, automatic stabilizers, BMA

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Abstrakt

Tato práce studuje vztah mezi daňovou progresí příjmů a volatilitou HDP. Analýzou našeho datasetu zahrnujícího 31 OECD států a za použití metody Bayesovského průměrování modelů (BMA) jsme ukázali, že vyšší progresivita daně z příjmů vede k nižší volatilitě HDP. Tento efekt je robustní k použití různých specifikací BMA a zároveň k různým způsobům měření daňové progrese. Pro tuto práci jsme použili nový způsob poměřovaní daňové progrese, který je založen na měření sklonu křivky průměrné daně. Dále jsme prokázali stabilizační efekt daňové progrese na volatilitu spotřeby a také na volatilitu odpracovaných hodin, které pokládáme za hlavní kanály pro stabilizační efekt daňové progrese na volatilitu HDP.

Klasifikace	E21, E32, F44, H24
Klíčová slova	daňová progrese, volatilita HDP, automatické stabilizátory, BMA

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Acronyms

BMA Bayesian Model Averaging

EU European Union

FE Fixed Effect

GDP Gross Domestic Product

IV Instrumental Variable

LP Liability Progression

OECD Organization for Economic Co-operation and Development

OLS Ordinary Least Squares

PIP Posterior Inclusion Probability

PIT Personal Income Tax

PMP Posterior Model Probability

RP Residual Income Progression

UIP Unit Information Prior

US United States

WB World Bank

Master's Thesis Proposal

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Proposed Topic:

The role of income tax progressivity in GDP smoothening : Empirical analysis

Motivation:

One of the main goals of political representation is to avoid high volatility of GDP and ensure long-term smooth growth of the economy. Proper fiscal policy might offer few automatic stabiliser of the business cycle fluctuations. Such stabiliser is and countercyclical tool that works automatically and immediately (unemployment benefits). For example, it has been shown that the size of the government is negatively correlated with GDP fluctuations (Fatas, A., Mihov, I., 2001) an therefore serves as a good automatic stabiliser. However, the evidence is not strong in case of tax progressivity, even though it behaves counter cyclically, as well. Let's suppose the income tax is progressive. Than the tax liabilities decreases by higher proportion than the taxable income, during the economic down-turn, leaving free resources in the economy. Vice-versa the tax liabilities grow faster, than taxable income if the economy is growing resulting in less volatile GDP (Attinasi, M. G. et al., 2011). The progressive income tax leaves more resources to the households at the expanse of the government in the slowdown and vice versa. The question should not be just if the tax progressivity works as an automatic stabiliser, but also how and through which channels. As the consumption of households is more sensitive to changes in disposable income than government expenditures, I believe the most significant (negative) correlation is between the volatility of consumption and tax progressivity. It will be also interesting to analyse this stabilisation effect for different group of countries such as: developing x developed or European (continental) x Anglo Saxon countries.

Hypotheses:

1. Hypothesis #1: There is a significant correlation between tax progressivity and GDP volatility
2. Hypothesis #2: If we decompose the GDP the correlation is the most significant between tax progressivity and consumption volatility.
3. Hypothesis #3: The effect of automatic stabilisation of tax progressivity is higher and more significant in developed European countries.

Methodology:

To conduct this research I first need to find a proper measure of tax progressivity. Attinasi, M. G. et al., (2011) uses index of progressivity based on the ratio of marginal tax rate and average tax rate of average production worker. This offers only limited description of progressivity so I will also rely on forthcoming Plato index developed by A. Cobham, E.V.K. FitzGerald and P. Janský and defined as the ratio of non-corporate direct tax paid to the gross income of top quintile households (direct tax includes social security payments). I will than evaluate the differences in results of individual measures. The data on GDP, consumption, government expenditures and investments will be searched at the World bank databases, which offers these data for many developed and developing countries for few decades. I expect to collect panel dataset including newest data for 2014. The final data set will be examined by standard econometric models as pooled OLS, fixed effect, random effect as well as assessing simple correlations. Based on the results I will also employ some grouping of individual years. As the dependent variable I will not use only the GDP volatility, but also consumption volatility, investments volatility and government expenditure volatility. Such decomposition of GDP volatility will allow me to better explain the GDP smoothening.

Expected Contribution:

Moldovan, R. (2010) studies the role of taxes as automatic stabiliser in context of neoclassical model with monopolistic competition, however, the empirical analysis of real data is still needed. To my knowledge Attinasi, M. G. et al., (2011) is the only paper empirically assessing the role of tax progressivity on GDP volatility, using real macroeconomic data. In previous works, the statement that progressivity of income taxes might behave as automatic stabiliser was somehow minor and not very well explained or studied. My contribution will be in employing another robust measure of tax progressivity, the Plato index, collecting new data (including years of financial crisis) for larger, not only OECD, number of countries. This new dataset will offer another results that will be compared to existing results from Attinasi, M. G. et al., (2011). Further, I will decompose the GDP volatility, so my thesis should offer better understanding of the role of tax progressivity in GDP smoothening. I am also going to compare the magnitudes of the studied effect for different groups of countries (i.e. developing x developed, continental Europe x Anglo Saxon countries). The recent data will allow to study the potential shift of the relationship after the crisis. This should shed some more light on the problematic.

Outline:

1. Introduction – motivation and overview of the paper
2. Literature review – I will present recent research in this field and its characteristics
3. Theoretical background – description of relevant theory
4. Data – data sources and descriptive statistics
5. Methodology – Presentation and justification of models and methods used in the paper
6. Results and robustness checks
7. Conclusion

Core Bibliography:

Attinasi, M. G. et al., (2011) - ECB Working Paper No. 1380

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1 Introduction

One of the main goals of political representation is to ensure long-term growth and avoid high volatility in macroeconomic variables. Highly volatile economies usually experience more severe downturns when shock occurs and it is also difficult to make good medium to long-term decisions in volatile environment. While Easterly (2005) argues that macroeconomic policy does not matter for the economic development once the impact of intuitions is accounted for, a proper fiscal policy may provide automatic stabilisers which insulate the economy, to certain extent, from shocks to aggregate demand and this way decrease the volatility of output. Although automatic stabilisers are proposed as an explanation of the well-known stylized fact documented by Galí (1994) or Fatás and Mihov (2001) that larger governments are associated with lower output volatility, less attention was given to specific fiscal policies which may boost the automatic stabilization, such as unemployment benefits or other transfers.

Attinasi et al. (2011) point out that if the tax schedule is progressive it acts as an automatic stabiliser and reduces the volatility of disposable income and hence the consumption volatility and output volatility, for which they also provide empirical evidence. They also found stabilizing effect of tax progressivity on the investment volatility, while the effect on volatility of hours worked, found by Mattesini and Rossi (2012), is not present in their dataset.

This thesis aims to shed some more light on the role of tax progressivity as an automatic stabiliser, building on the work of Attinasi et al. (2011). Our contribution is then twofold: first, we construct a new measure of personal income tax progressivity based on the slope of the average tax curve. And second, this is the first empirical study of the effect of tax progressivity on output volatility using a Bayesian model averaging (BMA) approach, which allows us to employ more control variables and provide further evidence on this topic. Our hypothesis is that the output smoothening effect of tax progressivity is robust to the chosen estimation technique and also to different progressivity measures. Secondly, we believe the effect works through reducing consumption volatility and hours worked volatility and therefore higher tax progressivity mitigates the response of economy to aggregate demand shocks and also to productivity shocks.

The thesis is organised as follows: chapter 2 provides literature review focusing on several different aspects of the topic, chapter 3 describes the BMA technique with emphasis on understanding of different priors used in our empirical analysis, followed by chapter 4 describing our dataset of 31 OECD countries and including section on newly constructed measure of income tax progressivity. Chapter 5 provides main results of our analysis including some robustness checks, while chapter 6 concludes.

2 Literature review

2.1 What are automatic stabilisers?

The concept of automatic stabilisers was first formulated by Musgrave and Miller (1948) who define them as built in flexibility of tax-transfer system that ensures fall in tax revenues and increase in transfers during the recessions. According to the above definition, automatic stabilisers exhibit two main features. First, they follow the business cycle, and second, they start working immediately (automatically) without any time lag of implementation. The second feature distinguishes automatic stabilisers from discretionary policies that are dependent on political decisions and thus suffer from the lag of implementation. Moreover, discretionary policies have been used for pure electoral purposes in past (Sapir and Sekkat, 2002). Traditional automatic stabiliser discussed in the literature are unemployment benefits, see for example Gruber (1994). Unemployment increases during the recession so the government spends more on the benefits for unemployed helping them to smooth their income. According to Keynesian theory higher disposable income converts to higher consumption dampening the fall of GDP during the recession. This is in contrast with Ricardian equivalence stressing the irrelevance of timing of taxes because for given spending, the taxes will have to be paid sooner or later.

On the revenues side researchers have focused on overall revenues rather than inspecting various types of taxes. The exception is the work of Buettner and Fuest (2010) who found that corporate income tax helps to smooth the demand, and possibly the GDP, in Germany. Tax revenues are used to measure the size of government and its negative correlation with GDP volatility is well documented. Galí

(1994) shows that standard real business cycle model fails to account for this type of correlation that he finds in his OECD data set. The marginal destabilizing effect of tax revenues (total tax revenues/GDP) predicted by the model is in strong contrast with significant results of his empirical analysis suggesting stabilizing role of government size. Fatás and Mihov (2000, 2001) pointed out that Galí's (1994) model overlooks some important aspects of fiscal policy such as tax progressivity or countercyclical transfers - unemployment benefits. They provide further evidence of negative correlation between government size and business cycle fluctuations based on data from 20 OECD countries. Their results suggest that the correlation is not simply due to the stable level of government expenditures, because the negative correlation is present even for private GDP. However, they failed to identify the channel through which the government size smoothen the business cycle.

Buti et al. (2002) described one of possible pitfalls of automatic stabilization - the negative supply side effect. They argue that mechanisms of automatic fiscal stabilization usually allow economic agents to delay their adjustments to changes in economic conditions. For example, strong social security system makes workers less concerned with the possibility of being unemployed and thus rises the wage demands. As a consequence, the labour market is less flexible and the negative supply effect prevails in the economy at costs of economic efficiency.

2.2 Link between tax progressivity and automatic stabilisers

One of the built-in features of tax system that influence the link between disposable income and actual GDP is tax progressivity. If the tax system is progressive, tax liabilities decrease by higher proportion than taxable income during the economic down-turn, leaving free resources in the economy. Vice-versa the tax liabilities grow faster than taxable income if the economy is growing, resulting in less volatile disposable income (Attinasi et al., 2011). In another words, progressive income tax leaves more resources to the households at the expanse of the government in the slowdown and vice versa. Agell and Dillén (1994) complement Keynesian fixed price models by model with price-setting agents accounting for small menu-costs and price stickiness. In their model of monopolistic competition the progressive tax works as an automatic stabiliser because it affects the pricing mechanism. According to Agell and Dillén (1994) the progressive tax increases the steepness of marginal cost curve enhancing the price flexibility and resulting in lower output volatility in response to shifts in marginal revenue curve. On the other hand, Mattesini and Rossi (2012) ascribe the stabilizing effect of tax progression to the labour market. According to their results, the volatility of hours worked decreases as tax progressivity increases and consequently mitigates the response of output to external shocks. The intuition behind these results is rather simple: suppose a positive (negative) productivity shock, the output increases (decreases) as well as the marginal tax rate stimulating the workers to supply less (more) hours. Consequently the increase (decrease) of output is partly mitigated. Moldovan (2010) provides further evidence that progressive tax system may smooth out the business cycle by impacting the after tax income and therefore the consumption and hours worked via the substitution and wealth effect. The results suggest that while consumption, investments and consequently also the output are stabilized via this effect, the effect on volatility of hours worked is ambiguous. Moreover, he shows that the effect is stronger in monopolistic competition than in perfect competition.

All together four main channels how automatic stabilisers may operate were identified in the previous literature and summarized by McKay and Reis (2013). These are (i) the dominant disposable income effect as presented above (see Brown, 1955 for more) (ii) marginal incentives (Christiano, 1984), i.e. increase of effective tax rate in years of growth and decrease in slowdowns encouraging intertemporal substitution of work effort away from booms (iii) redistribution channel proposed by Blinder (1975) suggesting that redistribution may shift the wealth to individuals with higher propensity to consume and hence boost the aggregate demand and consumption and (iv) social insurance channel: policies aimed to enhance automatic stabilisers usually mitigate consequences of risks of households having direct impact on household's saving (Challe and Ragot, 2013). For example generous safety nets will encourage households to save less, making them more likely to be liquidity constrained when aggregate shock occurs (the implications of liquidity constrained households are described in next sub-chapter). If the income tax is progressive, it satisfies conditions necessary to work through all four channels. It makes the disposable income less volatile, changes marginal returns from working during the cycle, redistributes the income and partly also provides insurance.

Obviously, we cannot assume that making the tax system more and more progressive would indefinitely boost the positive effect (negative correlation) on output volatility and this is somehow formalised in paper written by Vanhala (2006) pointing out the importance of initial level of progression. According to the author's results, a revenue-neutral change to more progressive tax system when the tax system is already progressive results in lower output steady state, but more importantly it amplifies the response to shocks. On the other hand, increasing tax progressivity when the initial tax is proportional will decrease the output volatility and dampen the response to productivity shock and also its persistence in the economy is shorter. This idea is in line with work of Chen and Guo (2013) who studied the relationship of progressive taxation and equilibrium determinacy in real business cycle with productive government spending. Their analysis offers satisfactory explanation for the observed decrease of output volatility after the Tax reform act of 1986 which reduced the initially very progressive US tax schedule. More doubt about the stabilizing effect of progressive tax was raised by Fanti and Manfredi (2003), who investigated the dynamic effect of tax progression in multiplier-accelerator model concluding that increasing the coefficient of progression is output destabilizing.

2.3 The role of disposable income and consumption

The traditional theory of automatic stabilisers firmly relies on the link between disposable income and actual consumption. If we accept the simplest Keynesian consumption equation (i.e. $C = cY^D$), where Y^Dstands for disposable income and c for constant marginal propensity to consume, the negative (in terms of sign) effect of progressive tax on GDP volatility is inevitable, although it mostly affects the consumption. The conflict of this idea with Ricardian equivalence, suggesting that timing of taxes does not matter as for given spending taxes will have to be paid sooner or later was already mentioned above. However, there are several reasons why the Ricardian equivalence is likely to fail. Blanchard (2000) names four of them:

1. Death: Current tax payers might not be there to face the adjusted taxes in future

2. Myopia: The adjustments of taxes may be too far in the future to even think about it and adjust agent’s decisions.

3. Credit constraints: some people, also called rule-of-thumb consumers, might face difficulties to borrow against future income, thus their consumption is affected by disposable income.

4. Insurance: As long as the taxes are rather proportional than lump-sum, the uncertainty of labour income is reduced which affects consumption.

At least some portion of the market participants will be affected by one of the above four reasons. Hence, the progressive tax will influence their decisions and market outcomes. Kremer and Stähler (2013) introduce the rule-of-thumb consumers to real business cycles model with labour market frictions and identify significant differences in consumption paths of constrained and optimizing households. Consumption volatility increases in the progressivity of tax system in case of optimizers, while it reduces the consumption volatility for rule-of-thumb households. Kremer and Stähler (2013) explain the increase in optimizer's consumption volatility by inter-temporal consumption shifting and by the more volatile "disposable income". They present the so called income effect making the optimizers to consume more unpredictably due to stabilised employment and vacancy costs as a result of higher tax progression. At the same time, as productivity shock and its wage effect dies out over time, the future taxes are less affected by current productivity shocks, when the tax schedule is progressive. Therefore optimizing households expect higher tax rates after the negative productivity shocks and postpone some of their expected future income losses. The opposite intuition holds for the positive productivity shocks making the consumption of optimizing households more volatile. It follows from the above reasoning that the final effect of tax progressivity on consumption is determined by the amplitudes of individual effects or more precisely by the portion of rule-of-thumb households in the economy.

2.4 Empirical review

One of the first paper that analysed the effect of tax progression as an automatic stabiliser was written by Fatas and Mihov (2000) who analysed a sample of 20 OECD economies. However their study was rather simple and only complementary as they analysed several other fiscal policy tools. The simple regression of output volatility on the marginal tax rate as a measure of tax progressivity yields significant and negative relationship. However, if they include also average tax rate as a proxy for government size, it is difficult to distinguish which of these rates is more relevant for automatic stabilization as they both become insignificant because of their high collinearity.

Auerbach and Feenberg (2000) also studied the implications of marginal tax rate and concluded that its role as an automatic stabiliser is rather small. They studied the tax system of US economy through 80' and 90' and found a significant decrease in the stabilizing potential of marginal tax rate throughout the years. This could be attributed to Tax reform act of 1986 that reduced the marginal tax rates and overall progressivity of US tax schedule. According to their results the marginal tax rate in US in 1995 might offset from 2 to 8 percent of initial shock.

To our knowledge Attinasi et al. (2011) is the most complex empirical analysis of tax progressivity as an automatic stabiliser. The analysis is based on sample of OECD countries between years 1982 and 2009 and the authors could find supportive evidence for negative correlation of tax progressivity and output volatility in several different specifications of the model and for different estimating methods, from simple ordinary least squares (OLS) estimator through instrument variables (IV) to fixed effect models (FE). Comparing the results authors conclude that OLS estimator using averages over 7 years fixed windows is the most appropriate model yielding sufficiently reliable results. The negative coefficient of tax progressivity measure is significant at least at 5% confidence level for majority of model specifications and at 10% confidence level for the rest of model specifications accounting for other several more or less relevant variables. They constructed a tax progressivity measure based on the ratio of average tax rate and marginal tax rate of average production worker and used the standard deviation of log changes of real GDP over the time periods as a main measure of GDP volatility. The proposed model accounted also for openness of the economy, purchasing power parity, proxy for government size, measure of financial development and few variables to account for current economic situation. Attinasi et al. (2011) demonstrate the results on case of Switzerland in 2000 as follows: an increase of Swiss marginal tax rate, faced by average production worker, from 22.2% to 30.3% or a drop in average tax rate from 10.6% to 0.5%, corresponding to one standard deviation increase of the progressivity measure, would result in reduction of Switzerland's mean output volatility by 18% from 1.7 to 1.4. To further check the robustness of results, the authors performed other estimations using different volatility measures and alternative fixed-windows. We see the main shortcoming of this paper in its narrow measure of tax progressivity, which only measures the tax progressivity faced by single worker earning average wage. In fact, there might be nobody earning this average wage and the average and marginal tax rates faced by other income level workers could be significantly different. Therefore, we present a new measure of tax progressivity in chapter 4.

A similar approach was followed by Mattesini and Rossi (2012) who conducted short empirical analysis to verify a “side outcome” of their New Keynesian model with progressive labour taxes on sample of 24 OECD countries. Their progressivity measure is built on long run average tax rate and elasticity of the tax rate to the relevant tax base to correspond with the theoretical model. As a dependent variable they do not use only volatility of output, but complement their analysis by studying the effect of tax progressivity on inflation volatility and volatility of hours worked. The authors accounted for several control variables such as standard deviation of government purchases, standard deviation of the terms of trade, employment protection index and union density as variables capturing the features of labour market, identified as possible determinant of macroeconomic volatility (see for example Campolmi and Faia, 2011). They also include the dummy for EU members and control variable for size of the economy. The OLS estimates suggest that progressivity has significant (10% confidence level) impact on output volatility and enters the regression with negative sign. From the list of control variables only volatility of government expenditures, employment protection, and EU membership are significant. Employment protection enters with negative sign, while volatility of government expenditures and EU dummy variable with positive sign. The EU dummy variable might capture the effect of trade openness identified as important by Rodrik (1998) or Attinasi et al. (2011) and which is not accounted for in the regression of Mattesini and Rossi (2012). Regarding the other dependent variables, the authors found even more significant negative effects of tax progressivity on volatility of inflation and also, in contrast with Moldovan (2010), on hours worked.

Dolls et al. (2012) used a micro simulation models to study the tax-benefit system of 19 European countries and US economy to examine the extent to which the automatic stabilisers influence the household's disposable income and demand in presence of macroeconomic shocks. They found that the stabilizing effect is bit stronger in Europe compared to US economy, even though there is a great heterogeneity among European countries. This could be explained by on average higher tax progressivity in Europe. In case of proportional income shock, Dolls et al. (2012) estimated the stabilization effect of automatic stabilisers to reach up to 22% in the EU and 17% in the US. The differences are more significant in case of unemployment shock, where the cushioning effect was estimated to range from 13% to 30% for EU countries and from 7% to 20% for the US economy. It was also shown that automatic stabilisers are weaker in countries from south and east Europe compared to for example Nordic countries.

2.5 Progressivity measures

The progressive tax is defined as a tax levied at rate that increases in the tax base i.e. the larger the tax base the higher the tax rate. Therefore its marginal tax rate is higher than the steadily increasing average tax rate and if this holds for all levels of income the tax rate is said to be uniformly progressive (Røed and Strøm, 2002). The alternative, when the marginal tax rate is lower than the average tax rate, is said to be regressive, and if the marginal tax rate equals the average tax rate, the tax is proportional. So far this seems to be straight forward, however the problem emerges if we want to compare the degree of progressivity of two countries as it may vary with the income levels. It is not rare that the tax schedule is progressive for some income levels whereas it is proportional or even regressive for other income levels. Moreover, even if the marginal tax rate is higher than the average tax rate, the "degree" of tax progressivity, in sense of the steepness of average tax rate curve, will decrease with increasing level of income due to the fact that it does not make sense to set the marginal tax rate ≥ 100%. It is now evident that the average tax rate is capped by the highest marginal tax rate and will approach this rate if the income goes to infinity. According to Hemming and Keen (1983) the tax system is more progressive than another for a given pre-tax income distribution if and only if the Lorenz curve of after-tax income distribution given by the more progressive tax lies below or on the Lorenz curve given by the less progressive tax. The tax which satisfies the above condition for all pre-tax income distribution is said to be uniformly more progressive tax. Therefore a uniformly progressive tax as defined by (Røed and Strøm, 2002) is uniformly more progressive than proportional tax as defined by Hemming and Keen (1983). Even though this gives us some intuition how to compare individual tax systems it only leaves us with ordinal comparison and we would rather need a cardinal function describing the degree of tax progressivity so we can quantitatively analyze its effects.

It follows the above discussion that the first and very important issue of this analysis is to find a proper measure of the degree of tax progressivity. This measure should be (i) in line with the definition of progressive tax (ii) comparable across the years and as well across different countries (iii) capture the link between income tax revenues and household income distribution (iv) robust and yet simple. There were few different measures used in the previous literature that can be divided into two groups: the individual or local tax progressivity measures and global tax progressivity measures.

2.5.1 Local tax progressivity measures

The local progressivity measures are focusing on the degree of tax progression for each possible income. It measures by how much the average tax rate increases in income. Musgrave and Thin (1948) presented four local measures of income tax progressivity out of which two where extensively used in the literature, the liability progression and residual income progression (Kristjánsson and Lambert, 2014). The former, liability progression (LP), is the elasticity of tax liability with respect to pre-tax income and the latter, residual income progression (RP), is the elasticity of after-tax income with respect to income before tax. We can represent those measures by following functions of y:

$$LP(y) = \frac{MTR(y)}{ATR(y)}, ATR(y) > 0 \tag{2.1}$$

$$RP(y) = \frac{1 - MTR(y)}{1 - ATR(y)}, ATR(y) < 1 \tag{2.2}$$

Where y is the level of income, $MTR(y)$ stands for marginal tax rate and $ATR(y)$ for average tax rate for given y. It holds for both that positive flat or proportional income tax yields $LP = RP = 1$ for all y. If the tax is progressive $LP > 1$ and $RP < 1$ at least for some levels of income y. The regressive tax yields opposite results i.e. $LP < 1$ and $RP > 1$. Therefore the more progressive tax rate, the higher is the LP measure and the lower is the RP measure. Note that the residual income progression measure is defined also for zero tax rates.

The other two local measures defined by Musgrave and Thin (1948) are average tax rate progression - derivative of average tax rate with respect to pre-tax income, and marginal tax rate progression – derivative of marginal tax rate with respect to pre-tax income. However, these did not get as much attention in the literature so far.

Attinasi et al. (2011) defines his personal income tax measure as $1 - RP(w)$, where w is the income of average production worker, full time employed, not married and without children as reported by the standard OECD statistics. The main drawback of such measure is its narrow focus on average production worker. The RP for such a worker may be almost identical for two individual countries even though the tax schedule is completely different over the whole income distribution. It was also shown that married women may be much more important for a model's outcome then single men without children (Kniesner and Ziliak, 2002).

2.5.2 Global tax progressivity measures

Despite the described weaknesses of local tax measures, we can use them in the representative agent models without any loss of generality as these models rely on the fact that all agents (workers) are equal with the same income and therefore are subject to identical tax rate and tax progression. However, as pointed out by Røed and Strøm (2002) there is no reason to care about tax progression if all workers are equal as no redistribution would be required and the same amount of tax revenues could be collected by non-distortionary lump-sum tax at zero efficiency costs.

The global tax progressivity measures are designed to overcome this issue by focusing on the degree of redistribution and allowing for heterogeneity of income, workers, and their preferences about the trade-off between consumption and leisure. So far, there is no single generally accepted measure of global progressivity. Beside the four local measures, Musgrave and Thin (1948) presented also one global measure of tax progressivity, effective progression, lately redefined by Reynolds and Smolensky (1977), who built their measure on the difference of pre-tax and after-tax Gini coefficients for given income distribution. This kind of measures basically focuses on measuring the redistributive effect by comparing hypothetically proportional tax system, presented by pre-tax income, with after-tax income and hence account for various tax exemptions and tax allowances that usually make the system more progressive (Verbist and Figari, 2014). The tax system is said to be progressive if it decreases the inequality and so the redistribution effect is positive.

An influential global progressivity measure was constructed by Kakwani (1977) who measures the deviation of tax system from proportionality as difference between concentration coefficient of taxes[1] (C) and the Gini coefficient (G) of before-tax income:

$$K = C - G \tag{2.3}$$

Since these measures are based on Lorenz curve and tax concentration curve it is necessary to collect detailed micro data to be able to construct them and hence restrict the application to few countries.

A different approach was proposed by Ebert (1992). His global measure, built on the theory of local measures, takes the geometric average of residual income progressions for incomes of all workers in the economy.

[1] C can be also viewed as Gini index of tax liability, see Milanovic (1994) for more on concentration coefficient of taxes.

3 Methodology

As already pointed out in the literature review, in contrast with the effect of government size, the literature empirically investigating the relationship between output volatility and the income tax progressivity is relatively limited. In fact, to the current author's knowledge, there have been only two works presented on this topic and both, Attinasi et al. (2011) and Mattesini and Rossi (2012), heavily relied on OLS estimation with some extensions to IV and FE estimation in the former. If we follow these two papers we would suppose following standard linear regression model:

$$y = X\beta + \varepsilon \tag{3.1}$$

Where y is the $(n \times 1)$ vector of the dependent variable, GDP volatility measure in our case, X is the $(n \times k)$ design matrix, with k regressors, ε is the unobserved error term, and β being the $(n \times k)$ matrix of slope parameters we want to estimate. In such setting the researcher faces the model uncertainty issue widely addressed in growth literature including influential paper of Fernández et al. (2001a). The model uncertainty issue refers to the limited knowledge of the researcher about the true model resulting in possible inclusion of irrelevant regressors in the design matrix X which results in inefficiencies or even in overspecification bias. Similarly, omitting some important variable from the regression could result in omitted variable bias.

In our view the analysis of output volatility, which is in fact determined by different growth rates in consecutive years, suffers from the model uncertainty issue similarly to the growth analysis. Moreover, the aim of this work is to find evidence in the data for an effect of income tax progressivity on the GDP volatility, which could be seen as our uncertainty about including the measure of tax progressivity in the model. A widely used method, especially in growth literature, to deal with the model uncertainty is called Bayesian model averaging and we briefly describe some important characteristics of this method in following sections. Throughout the chapter we heavily rely on Koop (2003), Eicher et al. (2011), Feldkircher and Zeugner (2009), and Zeugner (2011)

3.1 Bayesian Theory

Bayesian econometrics is derived from few simple rules of probability making the methods extremely universal. This is also one of the main advantages that helped the Bayesian methods to become a popular approach among the researchers. Consider two random variables, A and B. Using the simple probability rules we can write:

$$p(A \cap B) = p(A|B)p(B) \tag{3.2}$$

Which simply says the joint probability density of random variables A and B "$p(A \cap B)$" equals to the conditional probability density of A, given B "$p(A|B)$" multiplied by the marginal probability density of B "$p(B)$". Similarly we can arrive to:

$$p(A \cap B) = p(B|A)p(A). \tag{3.3}$$

Merging equations (3.2) and (3.3) together and simple rearranging results in Bayes' theorem, the cornerstone for BMA and for whole Bayesian econometrics:

$$p(B|A) = \frac{p(A|B)p(B)}{p(A)} \tag{3.4}$$

To give the reader more intuition how the Bayes' theorem applies in data analysis, consider a matrix of data denoted D and θ being a matrix of the parameters for a model which tries to describe the D. For now, we want to learn about θ given the data D. Bayesian econometrics can help us by applying the equation (3.4). If we treat the θ as random variable[2], we can replace A by D and B by θ and arrive in:

$$p(\theta|D) = \frac{p(D|\theta)p(\theta)}{p(D)} \tag{3.5}$$

Our main interest here is the expression $p(\theta|D)$ (i.e. we are interested in using the data to learn about the parameters in a model), which is referred to as the posterior density. The term $p(D|\theta)$ is basically the probability density function for the data conditional on the parameters of the model, also called the data generating function and here referred as the likelihood function, $p(\theta)$ is referred to as prior density (Koop, 2003). In fact, the right hand side of the equation (3.5) uses the available data to update our prior believe about θ, resulting in posterior $p(\theta|D)$, which summarizes all the available information about the parameter θ. The BMA further builds on the equation (3.5).

3.2 Bayesian Model Averaging

To deal with the model uncertainty, BMA firstly estimates all the possible model specifications given the available data and secondly averages over all the models using their individual posterior probabilities as the weights. From this short description it is obvious that we are dealing with large amount of models. For k

[2] Bayesian theory believes the parameters of model are not given but as a random variable follow a probability distribution. Frequentist econometrics criticise this believe saying the parameter matrix θ is not a random variable. For more on the reasoning why Bayesian believes are appropriate see for example Poirier (1995).

available regressors, we have $K = 2^k$ possible subsets of those regressors and hence also 2^k models. Let us denote those models as M_i, where $i = 1, \ldots, K$. Then the posterior from equation (3.5) is model specific, so for model M_i we can write:

$$p(\theta^i|D, M_i) = \frac{p(D|\theta^i, M_i)p(\theta^i|M_i)}{p(D|M_i)} \quad (3.6)$$

So we have a posterior, likelihood, and prior for each model, which will allow us to derive the posterior model probabilities, $p(M_i|D)$, that are used as weights in the BMA. Using the equation (3.4) with $A = D$ and $B = M_i$, we obtain the crucial formula for computing the posterior model probability (PMP) of model M_i, which is afterwards used as the weight in BMA for the same model. The formula of PMP follows:

$$p(M_i|D) = \frac{p(D|M_i)p(M_i)}{p(D)} \quad (3.7)$$

Where $p(M_i)$ is called the prior model probability, and refers to researcher's expectations about the probability of model M_i being the correct one, before looking at the data. And $p(D|M_i)$ is the marginal likelihood (the probability density of the data, given the model M_i) which can be derived from equation (3.6). To do so, we have to integrate both sides of the equation with respect to θ^i and use the fact that the left hand side of equation (3.6) is the probability density function and therefore if we integrate it with respect to θ^i we get 1. After simple rearrangement we can arrive to the formula for the marginal likelihood:

$$p(D|M_i) = \int p(D|\theta^i, M_i)p(\theta^i|M_i)d\theta^i \quad (3.8)$$

The marginal likelihood depends on the likelihood function of the model M_i, which summarizes all the information about θ^i given the data D, and on the prior density. Now, we can derive the PMP from equation (3.7). Moreover, the denominator in equation (3.7), $p(D)$, is constant over all the models and thus simply multiplicative term in form of $\sum_{l=1}^{K} p(D|M_l)p(M_l)$. Therefore the PMP is proportional to marginal likelihood of the model times a prior model probability selected by the researcher. Formally we can write this proportionality as follows:

$$p(M_i|D) \propto p(D|M_i)p(M_i) \tag{3.9}$$

Following Eicher et al. (2011) let us break down data D to a dependent variable Y, set of candidate regressors, $X_1, \dots, X_k$, and a vector with n elements[3], all equal to 1, for the intercept. In such setting we have $K = 2^k$ different models. Model M_i has the form

$$Y = \alpha + \sum_{j=1}^{k_i} \beta_j^{(i)} X_j^{(i)} + \varepsilon \tag{3.10}$$

The $X_1^{(i)}, \dots, X_{k_i}^{(i)}$ is subset of $X_1, \dots, X_k$, $\beta^i = (\beta_1^{(i)}, \dots, \beta_{k_i}^{(i)})$ is a vector of regression coefficients to be estimated and $\varepsilon \sim N(0, \sigma^2)$ is the error term. Note that above we used θ^i which denotes the vector of parameters in M_i, $\theta^i = (\alpha, \beta^i, \sigma)$.

So far we know how to express the PMP, which is useful for comparison of individual models, however, we are more interested in the importance of candidate regressors. The BMA derives the posterior inclusion probability (PIP) of a candidate regressor, $p(\beta_j \neq 0|D)$, by summing the PMPs across the models where the candidate

[3] Note that we have n observations available.

regressor, X_j, is included. Hence, the PIP expresses the probability that the regressor has an effect on the dependent variable. We might also see this as a level of significance of the regressor, which is straightforward to interpret as the PIP is a probability measure. In the following analysis of the effect of income tax progressivity on GDP volatility, PIP is our sole measure of evidence for the effect, so it is important to mention, that PIP is reliable measure only under the condition that the regression parameters can be interpreted causally. This is violated if for example the GDP volatility determines the regressors rather than the other way round. This is a general endogeneity issue which we face also in the BMA (Eicher et al., 2011).

In the same way we obtained PIP, we can also obtain the model weighted posterior distribution for any parameter θ. Particularly, we sum up the model specific posteriors from equation (3.6) weighted by the PMP of the model across all the *K* models. Formally written as:

$$p(\theta|D) = \sum_{i=1}^{K} p(\theta|M_i, D)p(M_i|D) \tag{3.11}$$

The equation (3.11) provides us with theoretical ground for computing the posterior distribution of coefficients β and as such also for computing the posterior mean and posterior standard deviation of the BMA.

3.3 BMA and Zellner's g prior

In the previous section we describe the theoretical background of the BMA which is important to understand before analyzing the data. Even though the Bayesian theory is relatively straightforward, it requires complex algebra to find the solutions and if high number of candidate regressors is available the convenient computation can be practically infeasible. A common approach to this is employing Markov chain Monte

Carlo algorithm, however, these topics are beyond the scope of this work[4], and we restrict ourselves to necessary minimum which will be useful for better understanding of our analysis. For detailed description of computational framework see for example Hoeting et al. (1999), Koop (2003) or Fernández et al. (2001b).

According to Zeugner (2011) the posterior distributions $p(\theta|D, M_i)$, and marginal likelihoods $p(D|M_i)$ depends on the chosen estimation framework and the literature standard is to use a Bayesian linear model with a specific prior structure called Zellner's g prior, built on the work of Zellner (1986). This structure is particularly popular for its reduced elicitation of covariance structure and at the same time yields a simple expression for the marginal likelihood as shown below. The presented framework represents the necessary minimum which is important for understanding of the prior setting in the empirical analysis of this work.

To obtain the posterior distribution from equation (3.11) the researcher is required to place two types of priors. The model prior, $p(M_i)$, which is discussed later in this chapter, and the priors on model parameters, $(\alpha, \beta^i, \sigma)$. Fernández et al. (2001b) proposed following improper priors[5] on α and σ: $p(\alpha) \propto 1$ which corresponds to complete prior uncertainty where the prior is located, and similarly uninformative prior on $p(\sigma) \propto \sigma^{-1}$. The researchers are then formulating their prior (before looking at the data) believes on regression coefficients β^i into a normal distribution with specified mean and variance. We now heavily follow Feldkircher and Zeugner (2009)

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[4] In our empirical analysis we use 20 candidate regressors which allow us to go through all the models in reasonable time, and therefore, we do not have to rely on Markov chain Monte Carlo approximation.

[5] Zeugner (2011) states that the presented framework is very similar to the natural normal-gamma-conjugate model, which employs proper prior for α and that the resulting posterior statistics are virtually identical.

and Zeugner (2011) while presenting the importance of Zellner's g. The conservative approach is to assume a mean of zero of the coefficient, reflecting the limited knowledge about the coefficient. The variance structure is then defined according to Zellner's g: $\sigma^2(\frac{1}{g}X_i'X_i)^{-1}$:

$$\beta^i|g\sim N\left(0,\left(\frac{1}{g}X_i'X_i\right)^{-1}\right) \tag{3.12}$$

The expression (3.12) suggests that the researchers think the coefficients are zero and that the variance-covariance structure is somehow in line with the data X_i. The hyperparameter g indicates how certain the researchers are about their prior of coefficients being zero. The smaller the g, the more certain or conservative the researchers are as small g results in low prior coefficient variance. The other way round, large g means the researchers are uncertain about the coefficients being zero. Feldkircher and Zeugner (2009) show that for sample size $N > 2$ and given the g, the posterior distribution of coefficients follows the t-distribution with following expected value:

$$E(\beta^i|D, M_i, g) = \frac{g}{g+1}\beta_i^{OLS} \tag{3.13}$$

Where β_i^{OLS} is the standard OLS estimator for model M_i. It follows from (3.13) that the expected value of the coefficients is a convex combination of standard OLS estimator and prior mean, zero. Note that for $g \to \infty$ the coefficient estimator approaches the OLS estimator, and for $g \to 0$ the coefficient estimator approaches the prior mean, zero. Also the posterior covariance of $\beta^i$is affected by the choice of g:

$$\mathrm{Cov}\left(\beta^i \middle| D, g, M_i\right) = \frac{(y-\bar{y})'(y-\bar{y})}{N-3} \frac{g}{1+g} \left(1 - \frac{g}{1+g} R_i^2\right) (X_i' X_i)^{-1} \qquad (3.14)$$

Where $\bar{y}$ is the sample mean and R_i^2 is the OLS R-squared for model M_i. This prior framework results in the following simple marginal likelihood which includes penalty factor for model size p_i:

$$p(D|M_i, g) \propto (y-\bar{y})'(y-\bar{y})^{-\frac{N-1}{2}} (1+g)^{-\frac{p_i}{2}} \left(1 - \frac{g}{1+g}\right)^{-\frac{N-1}{2}} \qquad (3.15)$$

We include this section to demonstrate that the g prior directly influences the posterior mean, posterior covariance matrix and also the marginal likelihood. Few popular g priors are presented in following section.

3.4 Alternative formulations for Zellner's *g* prior

Under the presented framework of Zellner's g prior the researchers are only required to decide on the value of scalar hyperparameter, which should reflect their certainty about the coefficients being zero. Many different g priors have been developed and studied in the literature, with more or less sufficient outcome. This paper presents 3 such priors which were extensively used in the previous literature and proved to outperform its peers. Profound analysis and comparison of various g priors is provided in Liang et al. (2008), Eicher et al. (2011) or Fernández et al. (2001b).

The first prior we consider is the Unit information prior (UIP) which contains information approximately equal to the information contained in a single observation and was proposed by Kass and Wasserman (1995). This prior is built on Schwarz criterion (BIC) as the resulting posterior model probabilities are closely approximated by this criterion (Fernández et al., 2001b). In our framework of Zellner's g we can employ such UIP prior by setting the $g = N$. Eicher et al. (2011) who compared 12 candidate priors conclude that UIP prior together with uniform model prior (see next section) outperforms the rest on the simulated data as well as on growth data.

Fernández et al. (2001b) suggest using BRIC prior, which combines the UIP and another prior suggested by risk inflation criterion (RIC). In our framework this prior can be summarized as $g = \max(N, K^2)$. The authors argue that setting large g minimizes the prior impact on the results which represents the lack of prior knowledge. On the other hand, Ciccone and Jarociński (2010) show that large g might not be robust enough to some noise in the data.

The above two priors are fixed priors, so they assign same g to all the models. Liang et al. (2008) demonstrate that mixture of g priors may resolve some consistency issues and still provide computational tractability. They also propose a hyper g prior which is the preferred one by Feldkircher and Zeugner (2009). They suggest the shrinkage factor follows a Beta distribution in the following way: $\frac{g}{g+1} \sim \mathrm{Beta}\left(1, \frac{a}{2} - 1\right)$, where a is a parameter from the interval $(2,4]$. The prior expected value of the shrinkage factor is $E\left(\frac{g}{1+g}\right) = \frac{2}{a}$ and setting $a = 4$ implies prior shrinkage factor to be uniformly distributed over $[0,1]$, while $a \to 2$ corresponds to $g \to \infty$. A popular approach is to set the a parameter in a way that the $E\left(\frac{g}{1+g}\right) = \frac{N}{1+N}$ as it guarantees asymptotic consistency (Zeugner, 2011). In this paper if we refer to hyper g prior we refer to this setting.

3.5 Model Priors

Apart from the g prior, the researchers have to decide on the prior model probability to be able to compute the posterior model probability from the equation (3.7). Since there is usually a great number of candidate regressors combinations and therefore individual models, it would be very difficult and time demanding to assign each model individual probability. The relevance of such prior subjective choice would be also questionable. One way how to deal with this issue is to assign all the models the same probability, which was firstly suggested by Raftery (1988). Such prior is usually called uniform prior and has been commonly used in the literature. The possible drawback of this prior is that this kind of prior favours models with $\frac{K}{2}$ regressors, as there are simply more such models than models with $\frac{K}{2} \mp 1$ regressors etc..

Eicher et al. (2011) and Hoeting et al. (1999) present a more general model proposed by Mitchell and Beauchamp (1988) and defined as:

$$p(M_i) = \prod_{j=1}^{k} \pi_j^{\delta_{ij}} \left(1 - \pi_j\right)^{1-\delta_{ij}} \tag{3.16}$$

Where δ_{ij} equals to 1 if regressor X_j is included in model M_i and 0 otherwise and π_j is the prior probability that $\beta_j \neq 0$ in a regression model and it is usually assumed that $\pi_j = \pi$ for $j = 1, \dots, k$. Setting $\pi = 0.5$ for all models coincides with the uniform prior while $\pi < 0.5$ imposes a penalty for large models as the prior expected model size (m) can be derived as $m = \pi k$. Having this said, the researchers can express their prior believes about the model size (m) by setting the $\pi = \frac{m}{k}$. Throughout this work, we call this type of model prior a fixed prior.

Ley and Steel (2009) criticizes using of fixed model prior as uninformative prior, as it centres the mass of its distribution around the expected model size and therefore contains some information. They propose to treat the π from (3.16) as random variable drawn from Beta (a, b) distribution rahter than fixed parameter. The authors suggest to fix $a = 1$ as it allows for a wide range of prior behaviour and leads to reasonable prior assumptions. They also show the choice of m determines the parameter b in an equation $b = \frac{k-m}{m}$. The whole framework then generates a prior model size distribution that corresponds to the binomial-beta distribution implying an increase in prior uncertainty about model size (Ley and Steel, 2009). This type of model prior is also favoured over the uniform and fixed prior by Liang et al. (2008). In this paper we refer to this model prior as random prior.

4 Data

The corner stone of every empirical analysis are the data. In this section we describe the individual variables used in the analysis, its sources and some interesting statistics with particular emphasis on the measures of tax progressivity and output volatility. The whole data set is constructed from freely accessible databases of World Bank (WB), OECD, and European Commission (AMECO database)[6] and consists of data for 31 OECD countries[7] over 16 years between 2000 and 2015. Therefore, the dataset captures several pre-crisis as well as post-crisis years.

4.1 Volatility measures

The output volatility, as the main dependent variable, is measured by standard deviation of annual percentage growth rates of GDP per capita, as suggested by (Cariolle, 2012). The growth rates are based on constant local currency, and provided by WB. To be able to compute the volatility using standard deviations, one needs to choose the length of the period over which the volatility is measured. In this work a rolling standard deviation over seven-year windows, resulting in 10 periods in the dataset, is used. Seven-year window is suggested by Attinasi et al. (2011), but in contrast with their work, we opt for rolling window to end up with much higher number of time periods and observations. The mean of our volatility measure across 7-year rolling windows is 2.69, maximum value is 10.32 in the last period (i.e. 2009-

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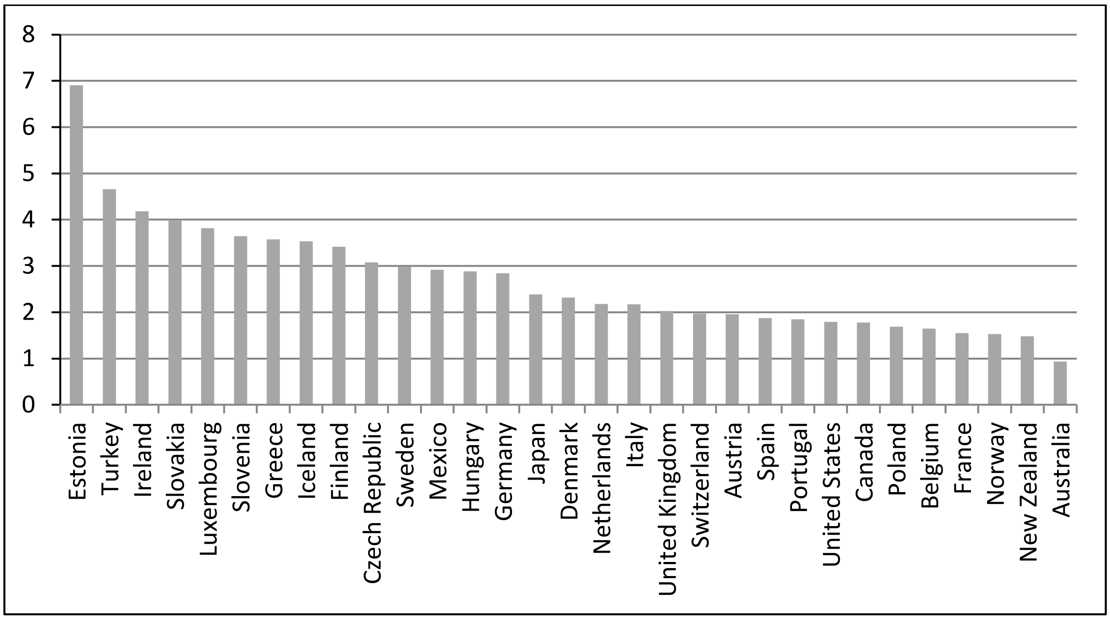
[6] EUROPA - Economic and Financial Affairs - Indicators -AMECO database , OECD Statistics, OECD data, Data | The World Bank

[7] List of the countries and description of the data and sources are available in Appendix A

2015) in Ireland and the lowest volatility throughout the dataset is in the second period (i.e. 2001-2007) in the United Kingdom. Highest average volatility over our 10 time periods was experienced in Estonia and the lowest in Austria. See figure 4-1 for comparison of average volatility.

Figure 4-1: Average volatility of GDP over 10 rolling windows



In our analysis we intend to provide some evidence on channels through which the tax progressivity may influence the output volatility. Therefore, we also study the impact of tax progressivity on volatility of consumption, investments, and government expenditures as the main determinants of GDP and also on volatility of hours worked, which directly impacts the output of given economy and which was identified as possible channel in the previous literature. All the volatility measures throughout this work are measured the same way as the output volatility, using the standard deviations of growth rates over 7-year rolling periods. The Consumption volatility[8] and Hours worked volatility are measured at per capita level, while the volatilities of Government expenditures and Investments are measured at the country level. The correlation coefficients of these “channel” variables with our GDP volatility measure are reported in table 4-1.

Table 4-1: Volatility Correlations

	Hours worked vol.	Consumption vol.	Investment vol.	Government expenditures vol.
GDP per capita vol.	0,196	0,284	-0,156	0,049

The correlation coefficients are not high, but the observed order where Consumption volatility reports highest and Government expenditures volatility lowest correlation with our measure of output volatility was expected. When later analyzing the data, it is important to have in mind that if we find similar effect of tax progressivity on volatility of consumption and government expenditures, the consumption is much more important channel due to its higher correlation with output volatility. Interestingly, the correlation coefficient of Investment volatility with the measure of output volatility is negative, suggesting that Investment volatility does not determines the output volatility.

4.2 Tax progressivity measures

To find the appropriate tax progressivity measure for our analysis is one of the main challenges of this thesis. Ideally we would use one of the global measures described in chapter 2, as in our view, those measures would be more relevant for our analysis than local measures. Unfortunately, none of the presented measures was available to us for recent years we want to analyse. Constructing such measure is not our intention

[8] Note that if we refer to our variables we use capital first letter, whereas if we generally write about volatility of some variables or about tax progressivity, we use lowercase letters.

as it is very time and also data demanding and whole new paper could be written on such topic. On the other hand, local measures are usually based on individual average and marginal tax rates which could be more easily changed by governments to adjust the tax progressivity. The measures are also more straightforward and easier to understand what is behind the individual measures.

We already criticized the PIT measure of Attinasi et al. (2011) for being too narrow in the way it measures only the progressivity faced by average production worker. Therefore, we construct a completely new measure of tax progressivity. As described in section 2.5. progressive tax system could be described as steadily increasing average tax rate in the tax base. When there is a flat tax, the average tax rate is constant over the different levels of tax base, and the regressive tax is characterized by decreasing average tax rate in the tax base. Having this said, it is obvious that the slope of average tax rate in tax base determines whether the tax system is progressive, regressive, or flat. Therefore, we see the slope of average tax curve as a good candidate to compare the level of progressivity in different countries. Regarding the data availability, we are restricted to rely on the OECD database[9] which provides marginal and average tax rates for 8 different family types. These include single workers earning 67%, 100%, and 167%[10] of average wage in given country, that

[9] The average and marginal tax rates are provided only for years from 2000 to 2015 which also restricts our dataset. Particularly, we use net personal average (marginal) tax rate.

[10] The other family types are: two earners married couple, one at 100% of average earnings and the other at 33% or 66% (two different family types) having 2 children. Next family type is the same as the previous one with the second earner at 33%, but without child, then one earner at 100% of average earnings married couple with 2 children and the last one is single person at 67% of average earnings with 2 children.

allow us to compute some proxy of the slope of average tax rate faced by single workers.

For now, we have three data points of the average tax rate curve of single worker for 67%, 100% and 167% income levels. For our final measure of tax progressivity we first compute the average slope of average tax rate curve between the average tax rates corresponding to 67% and 100% level of income and between 100% and 167% level of income separately. Secondly, we take an average of the two slopes to get some proxy measure of the overall steepness of the average tax rate curve. It might seem inconsistent to ascribe same weights to both slopes for the averaging, while one measures slope only across the length of 33 points and the second across the length of 67 points. However, we believe the density of individuals with earnings within the interval from 67% to 100% of average wage is significantly higher than density of individuals with earnings within the interval from 100% to 167% of average tax wage, as the wages are bounded from below and generally the median wage is usually lower than average wage. The inconsistency prevails, as our measure fails to account for the distribution of workers across the income levels, however, in contrast with PIT of Attinasi et al. (2011), it better captures the differences in tax progressivity faced by different types of workers. For the purpose of our analysis, we take averages of this measure over the 7-year rolling windows and call the measure Tax progressivity 1. According to this measure, the highest average tax progressivity over the ten studied time periods was faced by single workers in Ireland (2.05) and the lowest in Estonia, which also reported highest average volatility.

To be able to perform some robustness checks, we employ other two measures of tax progressivity, which are built on the PIT measure. In contrast with Attinasi et al.

(2011) we do not take only PIT faced by the average production worker, but compute the PIT for all the single workers with no child, and take their average to construct the second measure of tax progressivity, which we refer to as Tax progressivity 2. Tax progressivity 3 is then defined as average of PIT measure for all the family types as provided by OECD statistics, except the single worker with 2 children, as that one is subject to negative average tax rate for many countries which might bias the measure. All the tax progressivity measures are averaged over the 7-year rolling windows.

Table 4-2 captures the correlation coefficients among our three progressivity measures, PIT of average production worker (PITaw) as defined and used by Attinasi et al. (2011), and our GDP volatility measure.

Table 4-2: Correlation among tax progressivity measures and GDP volatility

	GDP p.c. vol.	Tax prog 1	Tax prog. 2	Tax prog. 3	PITaw
GDP p.c. vol.	1.000				
Tax prog 1	-0.016	1.000			
Tax prog. 2	-0.106	0.830	1.000		
Tax prog. 3	-0.132	0.712	0.838	1.000	
PIT	-0.051	0.579	0.660	0.709	1.000

The correlation of our main measure of tax progressivity with the measure of GDP volatility is low compared to other measures based on the PIT, however, the relevance of the measure is supported by high correlation with the other measures. At the same time the correlation of PIT measures with output volatility is increasing if we average over more family types. Overall, table 4-2 suggests our new measure is relevant, while it can provide some new evidence on the role of tax progressivity in GDP smoothening.

4.3 Control variables

To conduct meaningful analysis, we try to control for other relevant variables, which were found to affect the output volatility in previous literature. Using the BMA we do not deal with the model uncertainty, so we can afford to employ more control variables compared to similar studies.

Following the influential paper of Fatás and Mihov (2001) studying the effect of government size on GDP volatility, we control for the *Government size* as the well documented automatic stabiliser, *Terms of trade volatility* as the fundamental source of risk, *Openness* of the economy, as such economy is more sensitive to fluctuations of world markets, and *GDP per capita*. The authors also include variable capturing the sectoral specialization, which we substitute by two variables, first one capturing the share of employed people in industrial sector - *Industry* - and the second one in *Agriculture*. Mattesini and Rossi (2012) further use dummy variable accounting for *EU* membership and also included variables capturing the features of labour market, strictness of *Employment protection* and degree of centralization in labour contracts, *Union density*, as labour market institutions where shown to be important in explaining macroeconomic volatility (see for example Abbritti and Weber, 2010). Following Attinasi et al. (2011), we control also for volatility *Purchasing power parity* and level of *Urbanization*, even though the latter is in their paper only used as an instrument variable[11]. Except for the variables already mentioned, Easterly et al. (2001) in their large study of growth volatility determinants found evidence also for the effect of financial sector development, measured as the ratio of credit provided to public over the GDP - *Credit*, and *Inflation*, and following Cavallo (2009) we also

[11] Note that if urbanization is valid instrument, it is correlated with the output volatility.

include dummy for *Landlocked* countries, total *Population* and variable capturing *Education* measured as school enrolment rate. Cavallo (2009) also includes dummy variable for oil exporters, which we replace by variable capturing the total *Oil* production.

Jaimovich and Siu (2009) found that changes in the age composition of labour force matters in studying the business cycle volatility. Therefore we include control variable capturing the *Age dependency*. The 19th and last control variable we include in our dataset is *Life expectancy*, a well documented determinant of GDP growth, included by Bekaert et al. (2006) in their model explaining the growth volatility. Following Moral-Benito (2009) we take an average over the 7-year windows for flow variables, and for the stock variables, we take the value from the first year of given window.

While there might be other variables influencing the output volatility, for example volatility of money growth, for which we were not able to get sufficient data, compared to the papers of Attinasi et al. (2011) and Mattesini and Rossi (2012), studying the same phenomenon, we control for most of the variables they do, and add some more, which were shown or at least suspected to influence the output volatility.

5 Results

In this chapter, we present results of the empirical analysis studying the effect of the income tax progressivity on GDP volatility and possible channels of such effect. To derive the results, we use BMA technique outlined in Chapter 3, which has not been yet employed for the analysis of this effect. Therefore, BMA might shed more light on the role of tax progressivity in GDP smoothening. We start with a baseline model and latter provide robustness checks using different model as well as parameter priors. Section 5.3 then provides analysis of the tax progressivity on volatility of different components of GDP, and hours worked volatility. For the estimation we rely on BMS package in R software which was developed by Feldkircher and Zeugner (2009).

5.1 The Baseline Model

The baseline model and also the starting point of the empirical analysis is a Bayesian model averaging technique using model prior set as „uniform“ and g prior set to “UIP”. Table 5-1 shows the results of the baseline model using our dataset including the Tax progressivity measure 1 as the variable of our main interest and volatility of GDP per capita as dependent variable, described in chapter 4. The second column, posterior inclusion probability (PIP), expresses the importance of the variable in explaining the data as it equals to the sum of posterior model probabilities (PMP) of all models including the given variable. Throughout the chapter of results, we follow Eicher et al. (2012) and interpret the PIPs as follows: PIPs lower than 50% indicates lack of evidence for an effect, PIP in the range from 50% to 75% indicates weak evidence for an effect, PIP in the range from 75% to 95% indicates positive evidence for an effect, $95\% < PIP < 99\%$ indicates strong evidence for an effect, and finally $PIP > 99\%$ indicates decisive evidence for an effect.

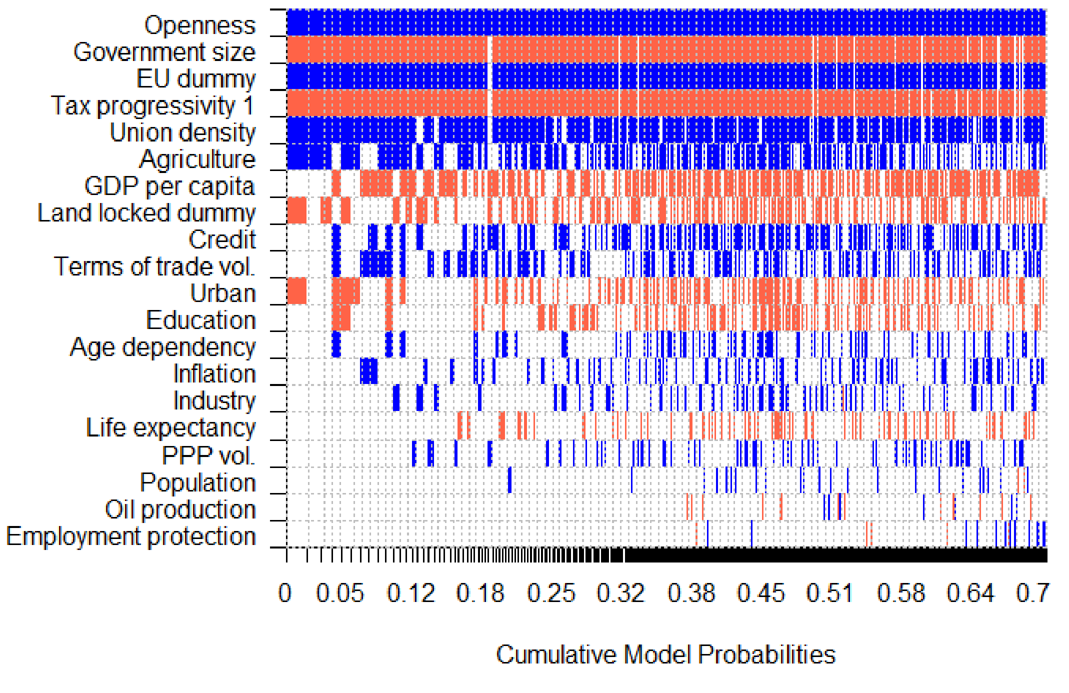
Table 5-1: Baseline model results

Dependent Variable: GDP per capita volatility

Variable Name	PIP	Unconditional Post. Mean	Unconditional Post. SD	Cond.Pos.Sign
Openness	99.9959%	0.029512	0.006130	1.00000
Government size	95.0797%	-0.082139	0.029847	0.00000
EU dummy	94.5664%	1.067495	0.399340	0.99999
Tax progressivity 1	92.4789%	-8.166170	3.345907	0.00000
Union density	80.8705%	0.015797	0.009572	0.99905
GDP per capita	57.7815%	-0.000017	0.000018	0.00004
Agriculture	57.0984%	0.090679	0.091832	0.99999
Credit	46.4194%	0.002062	0.002612	0.99953
Land locked dummy	46.1981%	-0.290516	0.364080	0.00000
Terms of trade vol.	37.5776%	0.044018	0.066320	0.99312
Urban	36.5457%	-0.008096	0.012589	0.00033
Education	32.8520%	-0.007734	0.012869	0.00000
Age dependency	24.1138%	0.012104	0.025925	0.99518
Inflation	23.7541%	0.019681	0.042664	0.98825
Industry	22.0111%	0.008216	0.020176	0.93393
PPP vol.	21.4787%	0.022788	0.053778	0.98560
Life expectancy	20.7440%	-0.019736	0.047827	0.00664
Oil production	9.4754%	0.000000	0.000001	0.28538
Population	8.7085%	0.000000	0.000001	0.86397
Employment protection	6.5286%	0.003309	0.038707	0.76155
Mean no. Regressors:	9.14		Model Prior:	uniform / 10
No. models visited:	1048576		g-Prior:	UIP
No. Observation:	301			

According to the outcome of the baseline model, only the covariate of Openness satisfies the 99% threshold indicating decisive effect. The importance of the economy's openness in explaining the GDP volatility was already well documented by Rodrik (1998) or more recently by di Giovanni and Levchenko (2009). We also find strong evidence for an effect of Government size, measured as percentage share of government revenues on GDP, which is the central focus of literature studying automatic stabilization (see for example Fatás and Mihov, 2001). There is a positive evidence for the effect of the EU dummy variable, and more importantly, for the effect of the Tax progressivity 1, which is the variable of our main interest. Particularly, there is a 92.48% probability that there is an effect of our progressivity measure on the GDP per capita volatility, according to the baseline model. This model also indicates positive evidence for an effect of Union density and weak evidence for an effect of GDP per capita and for variable capturing the share of people employed in agriculture sector in the total employment. We find lack of evidence for an effect of the remaining variables. To get a comprehensive visualization of models and PIPs see figure 5-1 showing 1000 best models.

Figure 5-1: Model Inclusion Based on 1000 Best Models (Baseline)



The blue colour (darker in grey scale) indicates positive coefficient, red colour (lighter in grey scale) corresponds to negative coefficient and white cell means the variable was not included in the model (i.e. zero coefficient). The models are scaled by PMP on the x axis. From this figure we can also see that the best model according to PMP includes covariates of Openness, Government Size, EU dummy, Tax progressivity 1, Union density, Agriculture, dummy for land locked countries, and measure of urbanization. However the PMP of this model is only 2%, which is rather low. Even though it is the best model, relying on the results of this individual model would be most probably misleading and therefore model averaging seems to be appropriate technique for our analysis. This figure also shows the importance of the Openness covariate, which is included in all the 1000 best models and together with the Government size, EU dummy and Tax progressivity 1 forms the building blocks of models explaining the volatility of GDP, which was already indicated by high PIPs.

The third column of table 5-1 shows the unconditional coefficients. These are weighted averages over all the models, including those where the respective covariate is not included, meaning the respective coefficient equals to zero. Posterior standard deviations (SD) are reported in the fourth column and the fifth column reports posterior probability of a positive coefficient of given covariate, conditional on its inclusion in the model. We can see that according to the baseline specification the effect of tax progressivity on GDP volatility has a negative sign in all model specifications where the variable was included.

Conditional coefficients, averaging only across the models where the respective covariates were included, are reported in

. Whereas unconditional coefficients can be seen as estimates of an effect adjusted for the probability of inclusion, the conditional coefficients captures only the estimated effect and therefore the absolute value of conditional coefficient is always higher or equal to the unconditional effect of given covariate.

To objectively compare the importance of individual variables and magnitudes of their effects, it is useful to look at the standardized coefficients, which we obtain if the dependent variable and all the regressors are normalized to mean 0 and variance 1 to bring them to the same order of magnitude. These standardized unconditional and conditional coefficients are also reported in

.

Table 5-2: Baseline Model Results (cont.)

Dependent Variable:	GDP per capita volatility					
			Standardized			
	Conditional		Unconditional		Conditional	
Variable Name	Post. Mean	Post. SD	Post. Mean	Post. SD	Post. Mean	Post. SD
Openness	0.030	0.006	0.533	0.111	0.533	0.111
Government size	-0.086	0.024	-0.361	0.131	-0.379	0.105
EU dummy	1.129	0.315	0.326	0.122	0.345	0.096
Tax progressivity 1	-8.830	2.498	-0.214	0.088	-0.231	0.065
Union density	0.020	0.006	0.206	0.125	0.254	0.083
GDP per capita	0.000	0.000	-0.159	0.162	-0.275	0.117
Agriculture	0.159	0.063	0.121	0.122	0.212	0.084
Credit	0.004	0.002	0.085	0.107	0.182	0.083
Land locked dummy	-0.629	0.272	-0.073	0.091	-0.158	0.068
Terms of trade vol.	0.117	0.056	0.061	0.093	0.163	0.078
Urban	-0.022	0.011	-0.057	0.088	-0.155	0.078
Education	-0.024	0.011	-0.035	0.059	-0.107	0.052
Age dependency	0.050	0.030	0.033	0.071	0.138	0.082
Inflation	0.083	0.049	0.033	0.073	0.141	0.084
Industry	0.037	0.028	0.028	0.070	0.129	0.096
PPP vol.	0.106	0.068	0.026	0.062	0.121	0.078
Life expectancy	-0.095	0.062	-0.035	0.084	-0.167	0.109
Oil production	0.000	0.000	-0.005	0.036	-0.052	0.107
Population	0.000	0.000	0.005	0.032	0.060	0.092
Employment protection	0.051	0.143	0.002	0.018	0.024	0.067

The order by magnitude highly correlates with the order by PIP (i.e. regressors with high PIP seems to be important also in term of the magnitudes). In this baseline setting, the tax progressivity seems to be an important determinant of GDP volatility as higher importance could be only ascribed to the well documented effects of

Government size, Openness, and also to dummy variable capturing the membership in EU, which could be seen as another indicator of economy openness. The magnitude of the effect of tax progressivity corresponds to 40% of magnitude of the effect of Openness and to 59% of the magnitude of the effect of Government size. Regarding the standardized conditional coefficients, all the coefficients are obviously higher and the difference is increasing with decreasing PIP. In contrast with the unconditional coefficients, the conditional coefficients of Union density and GDP per capita are higher than that of Tax progressivity, which indicates the effects of Union density and GDP per capita on GDP volatility could have higher magnitudes but we are more uncertain about the inclusion of those variables in the true model compared to tax progressivity measure.

Using the uniform model prior, one assigns the same prior probability to every single combination of covariates, which puts the most of the probability mass to models with $\frac{k}{2}$ regressors, where k is the number of explanatory variables, as there is simply more models with $\frac{k}{2}$ regressors then models with $\frac{k}{2}-1$ or $\frac{k}{2}+1$ regressors. As in our dataset k=20, using the uniform model prior, we favour models of size 10. However, the results also report mean number of regressors, which in our baseline setting equals to 9.14. One can come to this number by summing up the PIPs of all variables.

Figure 5-2 depicts the prior and posterior model size distribution. The difference is significant so we try to estimate the model using a different model prior and setting the expected model size to 9 as suggested by baseline model. From now on, we are only reporting results for variables with PIP higher than 50%, while using the same dataset of 20 regressors.

Figure 5-2: Posterior Model Size Distribution

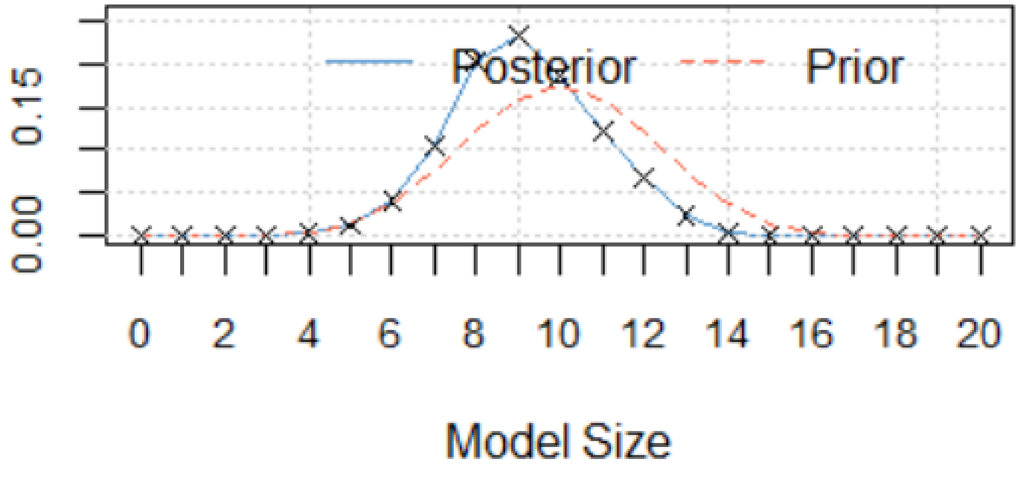


Table 5-3: Results with Fixed Prior

Dependent Variable: GDP per capita volatility

Variable Name	PIP	Unconditional Post. Mean	Unconditional Post. SD	Cond.Pos.Sign
Openness	99.9954%	0.029141	0.006052	1.000000
Government Size	91.7648%	-0.079500	0.033546	0.000000
EU dummy	90.8796%	1.014577	0.442101	0.999991
Tax Progressivity 1	88.5132%	-7.806118	3.683108	0.000000
Union Density	76.8194%	0.014925	0.009902	0.998610
Agriculture	55.5211%	0.090150	0.092811	0.999986
GDP per capita	55.0240%	-0.000017	0.000018	0.000039
Mean no. regressors	8.54		Model Prior	Fixed/ 9
No. models visited	1048576		g-Prior	UIP
No. Obs.	301			

Table 5-3 reports the results when using the fixed model prior and setting the prior model size to 9. The posterior model size drops to roughly 8.5 implying that PIPs of some variables had to decrease as well. The openness of the economy keeps its high PIP, while the rest of the variables, satisfying the condition of PIP>50%, reports lower PIPs. In case of Tax progressivity 1 it decreases by 4 percentage points to 88.5% indicating positive evidence for an effect. Also the posterior mean slightly decreases, however, this is attributable to lower PIP, as if we compare the conditional coefficients, reported in table 5-4, the difference when using uniform or fixed model prior is negligible. Despite the lower PIP and slight decrease of the unconditional posterior mean there is still a positive evidence for the effect, and the effect of tax progressivity on GDP volatility has negative sign in all the models, where included. Looking at the standardized coefficients, the results are similar to those of baseline specification and Tax progressivity ranks 4th in terms of magnitude of unconditional coefficients and 6th when comparing magnitudes of standardized conditional coefficients.

Table 5-4: Results with Fixed Priod (cont.)

Dependent Variable: GDP per capita volatility

	Conditional		Standardized Unconditional		Standardized Conditional	
Variable Name	**Post. Mean**	**Post. SD**	**Post. Mean**	**Post. SD**	**Post. Mean**	**Post. SD**
Openness	0.0291	0.0060	0.5267	0.1094	0.5267	0.1093
Government Size	-0.0866	0.0247	-0.3491	0.1473	-0.3805	0.1083
EU dummy	1.1164	0.3184	0.3100	0.1351	0.3411	0.0973
Tax Progressivity 1	-8.8192	2.5282	-0.2046	0.0966	-0.2312	0.0663
Union Density	0.0194	0.0063	0.1944	0.1289	0.2530	0.0825
Agriculture	0.1624	0.0615	0.1202	0.1237	0.2164	0.0820
GDP per capita	0.0000	0.0000	-0.1531	0.1636	-0.2783	0.1176

The best model, with PMP of 2.5%, according to the setting with fixed model prior and prior model size of 9 includes the following variables: Openness, Government size, EU dummy, Tax progressivity 1, Union density, and Agriculture, and therefore favours more parsimonious models, as it does not include Urban and dummy for landlocked countries in contrast with the baseline specification using uniform model prior. Interestingly, the best model of the baseline setting is the second best model of the specification with fixed model prior, and vice versa.

The third and the last model prior we employ is the random prior. However, when setting the prior model size to 9 the resulting posterior model size was just a little below 8 and therefore, we opt for the prior model size set to 8. The results of most important regressors are reported in table 5-5.

Table 5-5: Results with Random Prior

Dependent Variable: **GDP per capita volatility**

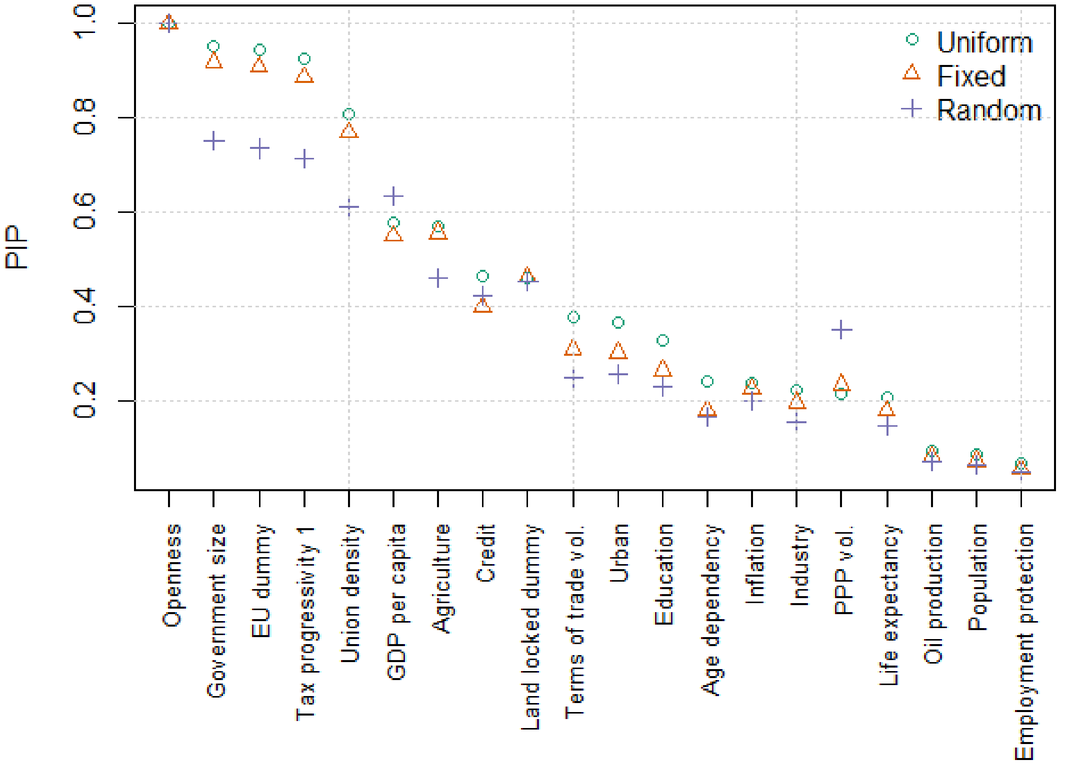
Variable Name	PIP	Unconditional Post. Mean	Unconditional Post. SD	Cond.Pos.Sign
Openness	99.9964%	0.029771	0.006087	1.000000
Government Size	75.0771%	-0.063747	0.043151	0.000000
EU dummy	73.4579%	0.815789	0.564859	0.999974
Tax Progressivity 1	71.2623%	-6.255298	4.535477	0.000000
GDP per capita	63.5349%	-0.000021	0.000019	0.000024
Union density	61.3108%	0.011865	0.010689	0.997464
Mean no. regressors	7.72		Model Prior	Random/ 8
No. models visited	1048576		g-Prior	UIP
No. Obs.	301			

The posterior model size is 7.72 so the prior model size 8 seems more appropriate than 9. The results reconfirm the importance of economy openness in explaining the GDP volatility. The rest of the variables report lower PIPs and also lower coefficients, which partly results from the lower PIPs. The PIP of Tax Progressivity drops to 71% and indicates only weak evidence for an effect. Conditional posterior mean of Tax Progressivity remains roughly the same as well as the posterior standard deviation. The standardized coefficients are similar to the results of uniform and fixed model priors.

Model with the highest PMP of 3.9% includes following regressors: Openness, Government size, EU dummy, Tax Progressivity, Union density, and Agriculture. Almost the same PMP is assigned to model including only Openness, GDP per capita and volatility of purchasing power parity. This somehow differentiates the random model prior from the previous priors, as for the first time, Government size, EU dummy, but also the point of our interest, Tax progressivity 1, are not included in the second and the third best models.

Figure 5-3 summarizes the PIP results of above described settings, using *g* prior set to UIP and three different model priors, in a comprehensive way.

Figure 5-3 Comparison of Model Outcomes under Different Model Priors



The Openness of the economy is confirmed by all three model priors as the most important determinant of the GDP volatility in our dataset and the resulting PIPs are almost overlapping. Beside the openness, the best rated models according to PMP are heavily relying on Government size, EU dummy, and in line with our hypothesis also on the tax progressivity measure. The exception is random model prior where the evidence for an effect of those three variables is weaker. Even more important result which coincides for all three model priors presented above is that the effect of tax progressivity has negative sign in all the models (variables combinations), where included.

5.2 The endogeneity issue:

The advantage of using BMA has been already stated, however, the endogeneity problem remains an issue. If any of the explanatory variables is correlated with the idiosyncratic error term, the estimation arrives to biased and inconsistent coefficients. In the previous literature two of our explanatory variables were suspected to be endogenous when estimating the effect on GDP volatility. Rodrik (1998) shows the government size might be endogenous as the citizens of largely open and thus highly volatile economies tend to opt for bigger governments, resulting in problem of simultaneous causality. Fatás and Mihov (2001) conclude the effect of government size on GDP volatility is biased if they do not account for endogeneity. On the other hand, Martinez-Mongay and Sekkat (2005) did not find evidence to reject the exogeneity of government size. Easterly et al. (2001) identified also the ratio of credit provided to the private sector to GDP to be endogenous, using standard Hausman test for the results of their analysis of determinants of GDP volatility, while Debrun and Kapoor (2010) could not reject the exogeneity of this variable.

In this paper we deal with the endogeneity issue by simple data adjustment. For the baseline model we used averaged values of variables Credit and Government size over the whole 7-year windows. But now, to avoid possible simultaneous causality, we take the value of the first year of each period. These new explanatory variables should reduce the probability that simultaneous correlation is present. In fact, we are somehow lagging the suspected variable, which is not perfect, but common technique how to deal with the issue of endogeneity and at the same time easily applicable to

BMA estimation. Similar approach was adopted for example by Rumler and Scharler (2011). Moreover, we are not truly interested in the exact effects of government size and credit, as the variable of our interest is the tax progressivity. However, the estimated coefficient of tax progressivity would be biased if the covariate is correlated with one of the endogenous variables.

We do not suspect tax progressivity to suffer from endogeneity issue, referring to Attinasi et al. (2011) explaining that the level of tax progressivity reflects rather societal preferences for equality and redistribution, or efficiency considerations rather than stabilizing efforts. To check this assumption, we perform standard IV estimation with lagged values of Tax progressivity 1 as an instrument for possibly endogenous variable Tax progressivity 1. The IV estimation yields similar result as standard OLS and using both, Durbin statistics and Hausmann – Wu statistics, we do not find evidence to reject the null hypothesis that the variables are exogenous[12]. Therefore, we proceed with unchanged Tax progressivity 1 and treating it as exogenous.

The results of BMA with “lagged” values of Government size and Credit, as described above, and using UIP as parameter prior and uniform model prior are reported in table 5-6. The estimated average posterior model size is 9.24, which is just a little higher than in the baseline specification (9.14), however the individual PIPs and coefficients differ significantly. The best model under this specification includes: Openness, Government size, EU dummy, Tax progressivity, Union density, GDP per capita, Terms of trade volatility, and also the Inflation.

[12] See Appendix B for detailed information on the IV estimation.

Table 5-6: Results with "lagged" Government Size and Credit

Dependent Variable: **GDP per capita volatility**

Variable Name	PIP	Unconditional Post. Mean	Unconditional Post. SD	Cond.Pos.Sign
Openness	99.9960%	0.028484	0.005900	1.000000
Government Size	99.7515%	-0.102825	0.021105	0.000000
EU dummy	99.5964%	1.239325	0.308042	1.000000
Tax Progressivity 1	98.7518%	-9.275179	2.557050	0.000000
Union density	96.6245%	0.022268	0.007352	0.999963
GDP per capita	61.3736%	-0.000018	0.000017	0.000041
Terms of Trade vol.	54.9739%	0.070096	0.074133	0.998938
Credit	39.2558%	0.001446	0.002105	0.999466
Mean no. regressors	9.24		Model Prior	Uniform
No. models visited	1048576		g-Prior	UIP
No. Obs.	302			

	Conditional		Standardized Unconditional		Standardized Conditional	
Variable Name	**Post. Mean**	**Post. SD**	**Post. Mean**	**Post. SD**	**Post. Mean**	**Post. SD**
Openness	0.0285	0.0059	0.5150	0.1067	0.5150	0.1066
Government Size	-0.1031	0.0205	-0.4590	0.0942	-0.4602	0.0915
EU dummy	1.2443	0.2984	0.3795	0.0943	0.3811	0.0914
Tax Progressivity 1	-9.3924	2.3495	-0.2431	0.0670	-0.2462	0.0616
Union density	0.0230	0.0062	0.2899	0.0957	0.3001	0.0803
GDP per capita	0.0000	0.0000	-0.1630	0.1540	-0.2655	0.1068
Terms of Trade vol.	0.1275	0.0517	0.0980	0.1037	0.1783	0.0724
Credit	0.0037	0.0017	0.0607	0.0884	0.1546	0.0733

The second-best model includes additional covariate Credit. Let us first have a look at the variables suspected from endogeneity. Using the lagged values, the PIP of Government size increased above 99% indicating decisive evidence for the effect, and also the absolute value of the coefficient grew by approximately 25%. On the other hand, both, PIP and estimated coefficient of the variable Credit decreased compared to baseline model. The differences in results compared to baseline specification suggest the endogeneity is present. In fact, the PIPs of all 4 corner stone variables including tax progressivity increased. The PIP of Tax progressivity indicates strong evidence for an effect and the estimated negative effect on GDP volatility is also larger. The conditional posterior sign is still negative with 100% probability (i.e. negative across all the averaged models), so our previous results regarding the effect of tax progressivity on GDP volatility seems to be robust to endogeneity issue of Government size and development of financial sector.

5.3 Different Priors:

In contrast with Eicher et al. (2011), Feldkircher and Zeugner (2009) found improved performance of BMA when using hyper g prior. Table 5-7 reports results of BMA using hyper g prior and random model prior with prior expected model size 8 as in previous chapter. Using random model prior is favoured setting of Ley and Steel (2009). Under the hyper g-prior, all of the variables within our dataset report PIP above 50% so there is at least weak evidence of an effect for all of them. High average PIP results in posterior mean of almost 16 regressors in the model, despite the prior model size set to conservative 8. The parameter a in the hyper g prior specification equals to 2.006645, which means the g is very close to unity and therefore the coefficients approach the OLS estimates[13]. As in the previous specifications, the most important variables in terms of PIP are Openness, EU dummy, Government size and Tax progressivity, all of them satisfying the threshold to indicate decisive evidence for an effect, while the coefficients are roughly the same as in baseline specification.

[13] When manually setting the parameter a to 3.5, ceteris paribus, the results are very similar.

Table 5-7: Results under Hyper g Prior and Random Model Prior

Dependent Variable: GDP per capita volatility

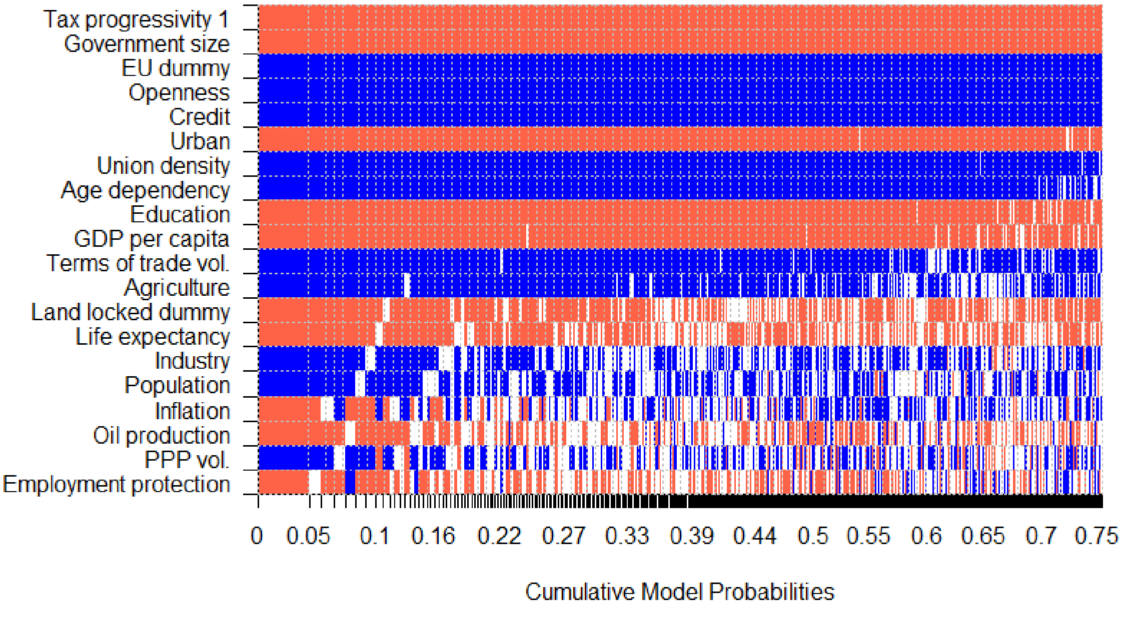
Variable Name	PIP	Unconditional Post. Mean	Unconditional Post. SD	Cond.Pos.Sign
Openness	99.9994%	0.030809	0.006157	1.000000
EU dummy	99.9183%	1.123036	0.281037	1.000000
Government Size	99.7977%	-0.073085	0.020524	0.000000
Tax Progressivity 1	99.6309%	-8.119800	2.361124	0.000000
Credit	96.0015%	0.004908	0.002145	0.999987
Union Density	95.8985%	0.016845	0.007401	0.999818
Urban	91.8930%	-0.023061	0.012424	0.000014
Education	90.5569%	-0.022141	0.012545	0.000000
GDP per capita	90.3245%	-0.000024	0.000014	0.000006
Age dependency	89.3609%	0.049304	0.029288	0.999929
Terms of Trade vol.	85.2944%	0.092923	0.065363	0.998555
Agriculture	79.5790%	0.085995	0.073475	0.999998
Land locked dummy	69.9712%	-0.246327	0.279980	0.000000
Life expectancy	65.0772%	-0.043932	0.060608	0.003366
Industry	60.8500%	0.012035	0.021920	0.947514
Inflation	55.2649%	0.009621	0.053738	0.638752
Population	55.1043%	0.000001	0.000002	0.925026
Oil production	54.7382%	-0.000001	0.000002	0.153486
PPP vol.	53.0949%	0.010005	0.057952	0.826610
Employment protection	50.9300%	-0.001714	0.099356	0.259802

Mean no. regressors	15.83		Model Prior	Random / 8
No. models visited	1048576		g-Prior	hyper (a=2.0066)
No. Obs.	301			

In contrast, much higher importance in explaining the GDP volatility is ascribed to covariate Credit. The PIP of Credit indicates strong evidence for an effect of this covariate and also the coefficient more than doubled compared to the baseline specification.

In terms of magnitude, comparing the standardized coefficients, Tax progressivity ranks 6^{th} when comparing both, conditional and unconditional coefficients. This results from overall higher PIPs, which means the difference in conditional and unconditional coefficients is not so big and therefore the Union density and also the GDP per capita keep their higher magnitudes even when averaged over the models where the variables are not included (coefficients equal to zero). The best model according to PMP under this BMA specification includes all our variables. The second best omits only Employment protection and third best omits covariate Inflation. In our view this undermines the reliability of this specification. Our dataset might not fully explain the GDP volatility and therefore the model using all the information available (i.e. including all the explanatory variables resulting in highest R-squared) is favoured. The best models are shown in figure 5-4. All of the 1000 best models include Tax progressivity and report coefficient of this covariate with negative sign.

Figure 5-4 : Inclusion Based on 1000 Best Models (Hyper g/Radnom)



Results under the hyper g prior and uniform model prior are reported in table 5-8. The PIPs still remain higher than those of baseline model, but lower than in previous model specification, resulting in posterior model size close to 13 regressors.

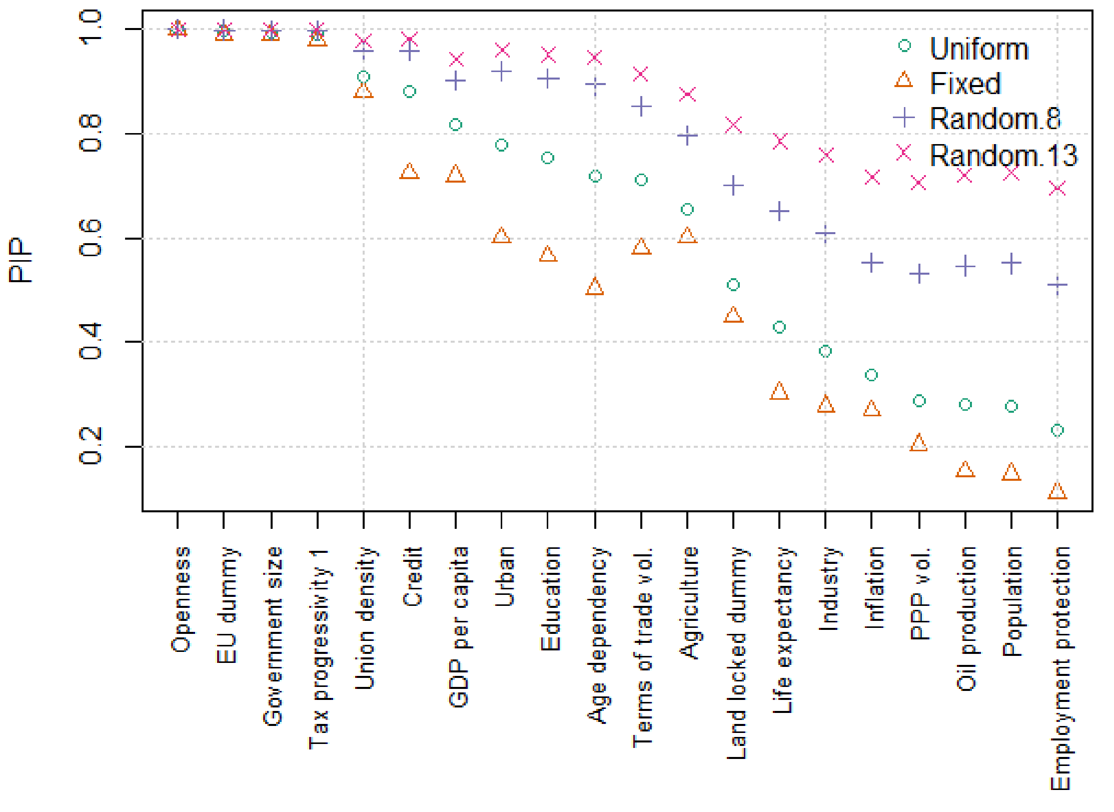
Table 5-8: Results under Hyper g Prior and Uniform Model Prior

Dependent Variable: GDP per capita volatility

Variable Name	PIP	Unconditional Post. Mean	Unconditional Post. SD	Cond.Pos.Sign
Openness	99.9980%	0.030158	0.006217	1.000000
EU dummy	99.7057%	1.102934	0.295595	1.000000
Government Size	99.4889%	-0.075280	0.021550	0.000000
Tax Progressivity 1	98.9076%	-8.142296	2.492984	0.000000
Union Density	91.0493%	0.016568	0.008076	0.999580
Credit	88.2562%	0.004296	0.002394	0.999935
GDP per capita	81.5708%	-0.000023	0.000016	0.000019
Urban	77.9102%	-0.018977	0.014016	0.000066
Education	75.5103%	-0.018293	0.014127	0.000000
Age dependency	71.9144%	0.038936	0.032872	0.999560
Terms of Trade vol.	71.0287%	0.080993	0.069681	0.995239
Agriculture	65.5802%	0.079432	0.077340	0.999989
Land locked dummy	51.0210%	-0.226129	0.298191	0.000002
Mean no. regressors	12.95		Model Prior	Uniform
No. models visited	1048576		g-Prior	hyper (a=2.0066)
No. Obs.	301			

Figure 5-7 summarizes the results of different model priors under hyper g prior. In addition to the above described random prior with prior model size 8 and uniform model prior, we report also random prior with prior model size set to 13, as suggested by mean number of regressors when using the uniform prior. This reports expected posterior model size equal to 17.5 so we also estimated random prior with model size set to 18 which, however, still reports higher posterior model size then prior model size, indicating that the results of random model prior under hyper g prior are somehow inconsistent. The last model prior included in figure 5-5 is the fixed prior with prior model size set to 13.

Figure 5-5: Results Comparison under Different Model Priors (Hyper g)



Despite our doubts about the results of random prior under hyper g prior, the results do not go against our hypothesis. Moreover the results of uniform and fixed prior are closer to those of the baseline specification and seem to be more reliable. Overall the hyper g prior confirms the four corner stone variables (Openness, Government size, EU dummy, Tax progressivity) as valid and ascribes them even higher PIPs, mostly indicating decisive evidence for an effect. Also the negative sign of the tax progressivity effect is confirmed. We do not rely on results using the hyper g prior, nevertheless important fact is the results do not contradict our previous findings when using the UIP prior.

We do not report results under another popular parameter prior described in the methodology as BRIC prior. The reason is that with our data set of 20 explanatory variables and 301 observations this prior yields very similar results as the UIP prior.

5.4 Breaking down the volatility of GDP

To shed some more light on the role of tax progressivity in GDP smoothening, we also regress our dataset on consumption volatility, investment volatility, government expenditures volatility, and volatility of hours worked. The results are shortly summarized in this section. For this analysis we only use the baseline specification of the model (i.e. g set to UIP together with uniform model prior), to reflect our limited knowledge about the true model and to keep the analysis simple.

Consumption volatility

Table 5-9 reports results[14] when consumption volatility is used as the dependent variable. Mean number of regressors equals to 11.56 and the importance of individual covariates changed significantly.

Table 5-9: Results with Consumption Volatility as the Dependent Variable

Dependent Variable: Consumption volatility

		Unconditional		
Variable Name	**PIP**	**Post. Mean**	**Post. SD**	**Cond.Pos.Sign**
Terms of Trade vol.	100.0000%	0.757217	0.118220	1.000000
GDP per capita	100.0000%	-0.000171	0.000025	0.000000
Government Size	100.0000%	-0.280819	0.038000	0.000000
Union Density	99.9991%	0.078242	0.015884	1.000000
Tax Progressivity 1	99.9990%	-23.524397	4.459092	0.000000
Openness	99.9833%	0.048588	0.010895	1.000000
Employment protection	98.7055%	-1.031399	0.293778	0.000000
Inflation	87.5127%	0.285310	0.178505	1.000000
Credit	79.0094%	0.009161	0.006090	1.000000
Industry	55.7040%	-0.062272	0.065039	0.000001
Mean no. regressors	11.56		Model Prior	Uniform
No. models visited	1048576		g-Prior	UIP
No. Obs.	301			

[14] From now on, only covariates with PIP>0.5 + tax progressivity measure are reported.

Within our dataset the explanation of consumption volatility heavily relies on Terms of trade volatility, GDP per capita, Government size, Union density, Tax progressivity and Openness of the economy, as their PIPs indicate decisive evidence for an effect. Our short and simple explanation of those effects is following: terms of trade itself reflect the level of consumption as if imports grow or exports decrease, most probably more is consumed within the country, and vice versa. Therefore also the volatility of the terms of trade is linked to volatility of consumption. Citizens of countries with higher GDP per capita have generally higher income, which allows them to better smooth the consumption over the business cycle and whole life. This is well documented in the literature (see for example Heckman, 1974). Bigger government usually provides larger safety nets which insure its citizens against severe income drop and helps to smooth their consumption. Rumler and Scharler (2011) see the union density as proxy for wage bargaining power and argue that strong unions may be less prone to adverse moderation in case of an adverse shock and thus higher union density leads to more volatile business cycle. The volatile business cycle might translate into volatile disposable income which affects the consumption volatility. In our view, the case of openness is similar to the union density in the way that more open economies suffer from larger impacts of adverse shocks which then translates to the volatility of consumption. The role of tax progressivity on disposable income and consumption smoothening was already described in the literature review.

In terms of standardized coefficients, or magnitudes, reported in table 5-10, the tax progressivity ranks sixth among the variables[15], and the size of the effect is comparable to the effect of tax progressivity on GDP volatility.

Table 5-10: Results with Consumption Volatility as the Dependent Variable (cont.)

Dependent Variable:	Consumption volatility					
			Standardized			
	Conditional		Unconditional		Conditional	
Variable Name	Post. Mean	Post. SD	Post. Mean	Post. SD	Post. Mean	Post. SD
Terms of Trade vol.	0.7572	0.1182	0.3899	0.0609	0.3899	0.0609
GDP per capita	-0.0002	0.0000	-0.5766	0.0855	-0.5766	0.0855
Government Size	-0.2808	0.0380	-0.4551	0.0616	-0.4551	0.0616
Union Density	0.0782	0.0159	0.3759	0.0763	0.3759	0.0763
Tax Progressivity 1	-23.5246	4.4585	-0.2275	0.0431	-0.2275	0.0431
Openness	0.0486	0.0109	0.3240	0.0727	0.3241	0.0725
Employment protection	-1.0449	0.2707	-0.1774	0.0505	-0.1797	0.0466
Inflation	0.3260	0.1521	0.1790	0.1120	0.2045	0.0954
Credit	0.0116	0.0043	0.1387	0.0922	0.1755	0.0655
Industry	-0.1118	0.0454	-0.0795	0.0831	-0.1428	0.0579

Investments Volatility

We proceed with inspection of the effect of tax progressivity on Investment volatility as another component of GDP. Compared to Consumption volatility and Government expenditures volatility, Investment volatility exhibits lowest volatility over our dataset. The estimates are reported in table 5-11. The PIP of tax progressivity indicates lack of evidence for an effect and the coefficient is much smaller than in case of GDP or consumption volatility. If we check the standardized conditional coefficient, to account for the lower PIP, the estimated size of effect of tax

[15] Highest magnitude of an effect is ascribed to GDP per capita, followed by government size, terms of trade volatility, union density, and openness.

progressivity on investment volatility is half of the size of the effect of tax progressivity on GDP volatility.

Table 5-11: Results with Investments Volatility as the Dependent Variable

Dependent Variable: Volatility of Investments

		Unconditional		
Variable Name	**PIP**	**Post. Mean**	**Post. SD**	**Cond.Pos.Sign**
Credit	100.0000%	-0.028448	0.004058	0.000000
Life expectancy	99.9991%	-0.696508	0.156234	0.000000
GDP per capita	99.9983%	0.000134	0.000032	1.000000
EU dummy	99.9616%	-2.574112	0.516734	0.000000
Oil production	99.8872%	-0.000021	0.000005	0.000000
Employment protection	95.4704%	-1.024971	0.378611	0.000000
Land locked dummy	83.9147%	-1.452909	0.830084	0.000000
Urban	63.9082%	0.034502	0.030963	1.000000
Openness	63.5091%	-0.021357	0.019224	0.000039
Tax Progressivity 1	44.8355%	-4.927818	6.339588	0.000000
Mean no. regressors	9.69		Model Prior	Uniform
No. models visited	1048576		g-Prior	UIP
No. Obs.	301			

The dataset is not tailor made for explaining the investment volatility, so the results are not fully reliable and for example the PIP of Tax progressivity could be even lower when including some other important variables determining the investment volatility. Having this in mind we do not find evidence for the stabilizing effect of tax progressivity on GDP volatility through stabilizing the level of investments. Our results of the effect of tax progressivity on Investments volatility are in contrast with results of Attinasi et al. (2011) and with findings of Moldovan (2010), who concludes that tax progressivity, via its impact on after tax income, stabilizes the level of consumption and investments, while the effect on hours worked is ambiguous. We report our estimates of BMA with volatility of hours worked as dependent variable bellow in this section.

Government expenditures volatility

Due to lack of the data on government spending, the presented results are based on only 262 observations, missing the following countries: Canada, Iceland, Mexico, New Zealand, and Turkey. We found a decisive evidence for an effect of Openness, Credit and Government size, while the PIP of Tax progressivity is below 10% so we lack any evidence indicating the tax progressivity influences the volatility of government expenditures. Moreover, the posterior probability of positive sign of Tax progressivity is more than 82%, which means that if there was any effect of Tax progressivity on volatility of Government expenditure, it would be rather volatility enhancing than stabilizing. In our view, the presented results disqualify government expenditures from being the channel through which the tax progressivity stabilizes the output.

Table 5-12: Results with Government Expenditures as the Dependent Variable

Dependent Variable: Government expenditures vol.

		Unconditional		
Variable Name	**PIP**	**Post. Mean**	**Post. SD**	**Cond.Pos.Sign**
Openness	99.9730%	0.054080	0.012956	1.000000
Credit	99.8672%	0.021252	0.005158	1.000000
Government Size	99.7157%	-0.228207	0.059165	0.000000
Inflation	98.5042%	-0.820340	0.270430	0.000000
Industry	97.0927%	0.185663	0.063696	1.000000
PPP vol.	77.4058%	0.753145	0.508281	1.000000
Urban	64.2155%	-0.043940	0.040002	0.000000
Population	55.8048%	-0.000008	0.000008	0.000026
Tax Progressivity 1	8.5719%	0.260019	2.160300	0.746633
Mean no. regressors	9.12		Model Prior	Uniform
No. models visited	1048576		g-Prior	UIP
No. Obs.	262			

Volatility of Hours worked

We close this chapter presenting estimates of BMA with volatility of hours worked as the dependent variable. Mattesini and Rossi (2012) identified hours worked as possible channel for the effect of tax progressivity on the output volatility. The coefficients of openness and tax progressivity as the only two covariates with PIP over 50% are reported in table 5-13.

Table 5-13: Results with Volatility of Hours Worked as the Dependent Variable

Dependent Variable: Volatility of Hours worked

		Unconditional		
Variable Name	**PIP**	**Post. Mean**	**Post. SD**	**Cond.Pos.Sign**
Openness	95.8479%	0.008725	0.003078	1.000000
Tax Progressivity 1	95.7526%	-5.433467	1.932840	0.000000
Mean no. regressors	3.37		Model Prior	Uniform
No. models visited	1048576		g-Prior	UIP
No. Obs.	301			

The posterior model size is estimated to relatively low 3.3 which reflects the low PIPs of the rest of variables as no other than reported covariates from our dataset reported PIP higher than 13%. The best model with PMP of 23% includes only the covariates of openness and tax progressivity, and the results indicate strong evidence for an effect of these variables. The estimated effect of tax progressivity is negative in all models and thus volatility decreasing and the standardized coefficient of tax progressivity is similar to the one from baseline specification when regressed on GDP volatility. The presented results justify the above presented idea that tax progressivity stabilizing effect works through marginal incentives presented by Christiano (1984), while they are in contrast with results of Attinasi et al. (2011), who finds positive but insignificant effect of tax progressivity on volatility of hours worked.

5.5 Different progressivity measures

To check robustness of our results, we employ two other measures of tax progressivity, described in chapter 4. In table 5-14 we report the coefficients only for the tax progressivity covariates as we are not interested in robustness of other results.

Table 5-14: Results Using Different Tax Progressivity Measures

Dependent Variable:	GDP per capita volatility				
Variable name	**Coefficient type**	**PIP**	**Post. Mean**	**Post. SD**	**Cond.Pos.Sign**
Tax Progressivity 2	Unconditional	**99.1920%**	-8.229816	2.163128	0.000000
	Standardized Unconditional		-0.279942	0.073580	
Tax Progressivity 3	Unconditional	**84.3574%**	-4.087582	2.314666	0.000000
	Standardized Unconditional		-0.161276	0.091326	
	No. models visited	1048576	Model Prior	Uniform	
	No. Obs.	301	g-Prior	UIP	

For the progressivity measure 2[16] we find decisive evidence for an effect, while for the progressivity measure 3[17] we find just positive evidence for the effect. Before further inspecting the results, the reader should realize that one measure is just an extension of the other. Particularly, Progressivity tax measure 3 does not average over PIT of single workers only, such as measure 2 does, but averages over another 4 family types. Moreover, the PITs of the other family types are usually higher than for the single workers, and therefore the measure 3 is higher than measure 2 for most of the observations. While this fact together with lower PIP of Progressivity measure

[16] Average of PIT measures as defined by Attinasi et al. (2011) for single workers earning 67%, 100%, and 167% of average wage, see chapter 4 for more.

[17] Average of PIT measures as defined by Attinasi et al. (2011) for all the family groups for which OECD reports the average and marginal tax rate, except one earner with two child. See chapter 4 for more information.

number 3 might partly explain the difference in unconditional posterior means, which is twice as high for measure 2 compared to measure 3, it fails to explain the difference between standardised conditional coefficients. These differences in the estimated coefficients, which can be hardly explained and mostly reflects the fundamental differences in the progressivity measures or the different priors used are the reasons why we avoid any deeper quantification of the effect of tax progressivity on the output volatility and we rather focus on the PIPs and evidence for the effect and on the direction of this effect, which both seems to be robust to our different progressivity measures.

6 Conclusion

We have investigated the effect of tax progressivity on GDP volatility using dataset of 31 OECD countries covering years from 2000 to 2015. We opted for BMA estimation technique, which allows us to employ 20 explanatory variables possibly affecting the output volatility, and overcome the issue of model uncertainty. To provide further robustness checks, we also employ three different progressivity measures, including completely new measure based on the slope of average tax rate curve, and two alternative measures extending the PIT measure defined in Attinasi et al. (2011). In contrast with PIT, our measures better captures the tax progressivity for different income levels and family types and does not solely focus on the average productivity worker.

Our results are broadly in line with the evidence provided by Attinasi et al. (2011) and Mattesini and Rossi (2012), and suggest that tax progressivity is an important determinant of GDP volatility. In fact, tax progressivity ranks among 4 most important determinants of GDP volatility within our dataset next to the well documented effects of openness of the economy (Rodrik, 1998), government size (Fatás and Mihov, 2001), and dummy for EU membership, which might be seen as another measure of economic openness. The effect is robust to different parameter and model priors as well as to different progressivity measures.

More importantly, we found very strong evidence that the effect of tax progressivity on output volatility has negative sign, which confirms our hypothesis that progressive taxation reduces output volatility. So far, the progressivity of tax system was mainly determined by societal preferences for the income redistribution or by efficiency considerations, but we confirm that the possible efficiency losses stemming from progressive taxation may be compensated by reduction of output volatility.

This thesis also provides evidence that the progressive tax system reduces volatility of private consumption and volatility of hours worked identified as the main channels for the stabilizing effect of tax progressivity on GDP volatility. Having this said, we see the progressive tax as a good measure to mitigate the negative response of the economy to aggregate demand shocks and productivity shocks. On the other hand, we conclude that the effect does not work through stabilizing the level of investments and government expenditures.

While our contribution is the newly proposed and employed tax progressivity measure and the BMA approach, which is used for the first time to study the role of tax progressivity in GDP smoothening, the future research should focus on extending the study beyond the OECD countries, inclusion of other control variables possibly affecting the output volatility, and if possible, employing also some global measure of tax progressivity. It would be also interesting to study the trade-off between efficiency losses and stability gains.

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Appendix A Data description

Table A-1: Data description

Variable	Description	Source
GDP per capita vol.	Standard deviaton of GDP per capita growth rates	WB
Progressivity measures	Own computation based on average and marginal tax rates of net personal income tax	OECD
Openness	Imports+Exports/2 measured as % share on total GDP	WB
Government size	Total tax reveunes measured as share % on GDP	OECD
EU dummy	=1 for EU member states	
Union density	The ratio of wage and salary earners that are trade union members, divided by the total number of wage and salary earners	OECD
GDP per capita	GDP per capita based on purchasing power parity. Constant 2011 international $	WB
Agriculture	Employment in Agriculture, % share of total employment	WB
Credit	Domestic credit provided by financial sector, % of GDP	WB
Land locked dummy	=1 for countries with no direct access to the sea	
Terms of trade vol.	The terms of trade effect equals capacity to import less exports of goods and services in constant prices. Standard deviation of changes.	WB
Urban	people living in urban areas as defined by national statistical offices. % of total population	
Education	Primary school enrollment, % of gross	WB
Age dependency	% of working-age population	WB
Inflation	Consumer price index (annual % growth)	WB
Industry	Employment in Industry, % share of total employment	WB
PPP vol.	GDP purchasing power parities :- Units of national currency per PPS (purchasing power standard), standard deviation of % changes	AMECO
Life expectancy	Life expectancy at bitrh (years)	WB
Oil production	Crude oil production thousand, tonne of oil equivalent	OECD
Population	Number of total population	AMECO
Employment protection	Index of strictness of employment protection	OECD
Consumption volatility	Private final consumption expenditure at current prices per head of population, standard deviation of % changes	AMECO
Investment volatility	Gross fixed capital formation, total economy, constant prices, standard deviation of % changes	AMECO
Government expenditures volatility	Government expenses (% of GDP), standard deviation of yearly % changes	WB
Hours worked volatility	Average annual hours actually worked per worker	OECD

Table A-2: List of countries included in the dataset

Australia	France	Luxembourg	Slovenia
Austria	Germany	Mexico	Spain
Belgium	Greece	Netherlands	Sweden
Canada	Hungary	New Zealand	Switzerland
Czech Republic	Iceland	Norway	Turkey
Denmark	Ireland	Poland	United Kingdom
Estonia	Italy	Portugal	United States
Finland	Japan	Slovakia	

Appendix B Exogeneity verification

To verify that tax progressivity enters our analysis exogeneously, we instrument the Tax progressivity 1 measure by its lagged values. In the standard IV estimation we also control for variables with PIP higher than 50% according to our baseline model. The results are estimated using software STATA and reported in the table below:

Table B-1: IV estimation Results

Dependent variable: GDP p. c. volatility

	Coefficient	Std.err	z	P>|z|	[95% Conf. Interval]	
Taxprogressivity1	-9.1373	2.3182	-3.94	0.000	-13.6808	-4.5938
Openess	0.0276	0.0033	8.36	0.000	0.0211	0.0341
Governmentsize	-0.0988	0.0176	-5.62	0.000	-0.1332	-0.0644
EU	1.0599	0.2317	4.57	0.000	0.6057	1.5141
UD	0.0234	0.0054	4.32	0.000	0.0128	0.0340
GDPpc	0.0000	0.0000	-2.32	0.020	0.0000	0.0000
Agriculture	0.1305	0.0518	2.52	0.012	0.0290	0.2320
_cons	4.8621	0.6124	7.94	0.000	3.6617	6.0625

Instrumented: Taxprogressivity1
Instruments: Openess Governmentsize EU UD GDPpc Agriculture Lagtax1

Here the variable Government size corresponds to the value in first year of given period as in section 5.2. The results confirm the significant negative effect of Tax progressivity on output volatility, but more importantly, STATA also provides Durbin statistics and Wu-Hausmann statistics and corresponding p-values to evaluate the null hypothesis that variables are exogenous:

Table B-2: Endogeneity Test

Ho: variables are exogenous
Durbin (score) chi(1) = 0.352825 (p = 0.5525)
Wu-Hausman F(1,263) = 0.341593 (p = 0.5594)

Based on these results, we can not reject the exogeneity of Tax progressivity 1 in our analysis.