Sources and Propagation Mechanisms of Foreign Disturbances in Small Open Economies: A Dynamic Factor Analysis*

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Abstract

This paper uses dynamic factor analysis to investigate the sources of foreign shocks and the propagation mechanism of these disturbances into two small open economies, Australia and Canada. Panels including a variety of foreign and domestic series for each country are used to estimate the factors. The specification of dynamics permits the computation of impulse responses which are used to suggest a structural interpretation of the factors. A small open economy model of the New Open Economy Macroeconomics is calibrated to contrast theoretical and empirical impulse responses. The results reveal that innovations in highly integrated equity markets are associated with comovements in investment which are crucial in explaining the cofluctuations in economic activity across countries. Therefore, the omission of traded capital goods in small open economy models represents an important shortcoming of theoretical frameworks in the literature.

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1. Introduction

A disjunction exists between the theoretical work on the sources and propagation mechanisms of disturbances across countries and the empirical investigation of this topic. Since the seminal work of Backus, Kehoe and Kydland (1992), it has been well documented, for instance, that macro aggregates exhibit comovements in several nations.[1] This observation has led to the development of various theoretical frameworks aimed at providing an explanation for the economic interdependencies evidenced, for example, with the synchronization of business cycles in many countries. Identifying the sources and propagation mechanisms of disturbances across economies, in order to better understand the observed commonalities in economic activity, remains, however, an unsolved and elusive empirical issue. In fact, there is no consensus on whether cofluctuations stem from a few common shocks simultaneously affecting several small and large countries, or from the transmission of disturbances originating in a few leading nations.

With regards to the theory, the literature on International Business Cycles (hereafter IRBC) has put forth a plethora of theoretical frameworks in order to explain precisely the nature of these comovements.[2] As a result, several models in this strand of literature -proposing a number of origins and channels for the propagation of shocks- have emerged.[3]

The New Open Economy Macroeconomics literature (abbreviated NOEM), advanced by the work of Obtsfeld and Rogoff (1995), offers an alternative theoretical approach to this issue. Specifically, this line of research highlights the role of monetary (and to lesser extent) fiscal shocks in explaining cross-country linkages in economic activity. More importantly, the propagation of disturbances in this framework is assumed to result from *consumption interdependencies* that are channeled through trade in *final goods* and driven, therefore, by the expenditure switching effects of exchange rate changes.

Interest in the origins and channels of transmission of shocks across countries arises not only from unresolved theoretical issues but also from policy considerations. This is particularly true for small open economies which are the focus of this paper. Given their dependence on exports,

[1] See Ambler et al. (1999) for a presentation of stylized facts in international business cycles, as well as for an exposition of various models in this field trying to replicate cofluctuations across countries.

[2] Baxter (1995) provides a good overview of open economy business cycle models in general. Greater emphasis has been placed on models considering two large countries as opposed to a large and small open economy which is the focus of the current study. Mendoza (1991) is one of the precursors of the analysis in the latter case.

[3] Amongst the candidates for explaining common cyclical fluctuations are: technology shocks, i.e. Solow residuals (Baxter and Crucini 1995, Zimmermann 1994b), terms of trade (Mendoza 1995) and (non-oil) commodity prices (Kose 2002), oil prices (Bakus and Crucini 1999), exchange rates (Zimmermann 1994a), and world real interest rates (Blankenau et al. 1999), amongst others.

imports of capital goods and foreign financing, it is reasonable to believe that countries with these characteristics are very susceptible to economic conditions abroad.

It has been well documented, for instance, that foreign disturbances have a substantial effect on the Australian business cycle. Nonetheless, researchers at the Reserve Bank of Australia have been perplexed in trying to understand the nature of these cofluctuations. As Gruen and Shuetrim (1994, p. 346) summarize,

> We have solid evidence that this process of internationalization has created strong links between Australia and foreign business cycles...however, discovering how foreign influences are now transmitted to the domestic business cycle is far less straightforward. In fact it is easier to find evidence against obvious channels [terms of trade and exports] than it is to find convincing evidence in favour of other channels.

An analysis of the roots and propagation of external shocks is also primordial to the design of monetary and exchange rate policy for these countries.[4] Appropriate policy responses to foreign disturbances, and, ultimately, whether or not it is optimal to insulate the economy from them, depends crucially on pinpointing how these innovations are propagated into these economies.[5] Other policy issues debated nowadays, such as the formation of common currency areas or discussions on policy coordination, also hinge on understanding the roots of international linkages in economic activity.

Although relevant for both academics and policymakers, for all reasons alluded to so far, empirical work in this area has not flourished as quickly as its theoretical counterpart. Despite the theoretical contributions from both strands of literature mentioned above, empirical work has failed to unveil the roots of cross-country interdependencies in output. To some extent, theory may have moved ahead of empirics and it remains to be seen if taking the models to the data might reveal shortcomings in the current frameworks and suggest additional avenues of research.[6][7]

[4] See the discussion in Canova and Marrinan (1996).

[5] Australia and Canada have conducted monetary policy in a framework of explicit inflation targeting. In this context, a shock generating increased activity and declining -or at least muted rises in- inflation (technology, for instance) might not trigger the same policy response as an expansionary disturbance with potential inflationary pressures (say, from wealth effects due to developments in equity markets).

[6] See Crucini (2001) for an example on how unresolved issues of measurement (such as the persistence of any possible common component in output across countries) can have substantial impact in discriminating amongst alternative IRBC models.

[7] In the IRBC literature, models are usually evaluated based on their ability to match empirical moments, particularly variances and correlations. As pointed by Schmitt-Grohé (1998), however, an assessment of models in this dimension implies knowledge of *both* all shocks hitting the economy and the channels through which

Studies dealing with the analysis of the origins and propagation of shocks across countries have relied on structural vector auto-regressions (SVARs) and, more recently, on factor models. However, dimensionality constraints, restrictive dynamics or difficulties in the identification of foreign disturbances, have not allowed researchers using these empirical frameworks to simultaneously consider a number of the theories dealing with cofluctuations. As a result, applied work in this field has not been able to identify which of the several sources and channels of transmission embraced by the theory are best supported by the data in small open economies.

In contrast to what has been done prior, this paper proposes to bridge theory and empirics. A comprehensive analysis of the origins and propagation mechanisms of foreign disturbances, from both an empirical and theoretical perspective -by studying the case of Australia and Canada- helps resolve the disjunction previously mentioned.

The particular choice of these two economies is due to the fact that these countries are paradigms of the standard textbook treatment of small open economies with a substantial share of output traded, well integrated into international capital markets and (at least over the last fifteen years) fairly stable flexible exchange rates.[8] Moreover, the geographical proximity of Canada to the US suggests that disturbances in the latter may exert substantial influence in the economic performance of the former. Therefore, the analysis of the US-Canada interdependencies represents a clear starting point for investigating the roots and transmission mechanisms of foreign shocks in small open economies. Given the geographical distance with its main trading partners (the US and Japan), including Australia, allows for an interesting contrast with the US-Canada case, and forces the consideration of disturbances potentially affecting a large number of economies in different regions.

The contribution of the present study is twofold, in terms of the methodology applied for analyzing the debate on the origins and propagation of foreign shocks, as well as in its empirical results, which have important implications for the theory of international comovements.

Regarding the empirical methodology, this paper estimates dynamic factor models, building therefore on previous work on dynamic factors by , Sargent and Quah (1983), Kaufmann (2000), as well as the Generalized Dynamic Factor Model (abbreviated GDFM) developed by Forni et. al. (2001). One crucial advantage of this method is that it permits analyzing the behavior

these are propagated. Given that, as as mentioned, these issues are far from settled, further empirical work would consequently permit to define better metrics with which to judge the performace of different theoretical frameworks.

[8] An additional reason for selecting these two countries for the analysis is the availability of fairly long time series, compiled by a unified source (OECD).

of a large number of series by inferring a small (relative to the variables in the panel) set of underlying shocks -the factors- responsible for all comovements across series. As a result, this method overcomes dimensionality constraints inherent to other empirical frameworks.

In international macroeconomics, factor models have been recently applied to estimate common components in output, which can account for the synchronization of business cycle fluctuations across countries, as in Bowden and Martin (1995), Lumsdaine and Prasad (1997) and Malek-Mansur (1999). The analysis here follows the work of Gregory, Head and Raynauld (1997) and Kose, Otrok and Whiteman (1998), however, in introducing an explicit dichotomy between domestic and foreign factors.

An element distinctive of the empirical model of this paper -compared to studies on cofluctuations which disaggregate the origin of shocks- is the inclusion of dynamics in a manner that allows variables to respond with varying speed to the factors. In this setting, impulse responses to the identified foreign factors can be computed for all variables included in the panels and their behavior studied in order to understand the roots and transmission mechanisms of foreign disturbances. The impulse responses are therefore used to suggest an interpretation of the factors. This approach has been pursued earlier -in a different setting- by Giannone, Reichlin and Sala (2002) and Sala (2001), who use the GDFM to provide a structural interpretation of the factors in their analysis of the conduct and transmission of monetary policy in the United States and the Euro area, respectively.

In summary, the estimation of dynamic factor models in this paper -one for Australia and one for Canada- permits an analysis of the sources and propagation mechanisms of foreign disturbances which is both *agnostic and comprehensive.* Exploiting this method's ability, as mentioned, to handle a large number of series, the inclusion of a diverse set of variables (37 for Australia and 34 for Canada) allows the simultaneous consideration of several different origins and transmitters/receptors of disturbances originating abroad, making this investigation *comprehensive.* Moreover, this can be done without any restrictions on which type of foreign disturbances (e.g. monetary, fiscal, technology, etc.) are responsible for comovements. As result, an *agnostic* stance is taken, allowing the data to reveal how the various theories dealing with the effects of external shocks in small open economies fare.

Regarding the results, the analysis of impulse responses to the inferred foreign factors, reveals that shocks originating in international equity market are a prime source of foreign disturbances that result in common fluctuations between the rest of the world and both Canada and Australia.

Moreover, the results highlight that international linkages in investment are a key channel for the propagation of external shocks in these countries, particularly given their dependence on imports of capital goods.

In order to contrast the results from factor analysis with the theory in international macroeconomics, this paper takes up the predictions of the NOEM by calibrating the small open economy model of McCallum and Nelson (2001). Theoretical impulse responses to a foreign output expansion are then contrasted with those estimated from the factors. The theoretical model correctly predicts that Canadian exports represent an instrumental channel for the commonalities in economic activity with the US. For Australia, contrary to the theory, exports cannot account for the role of external disturbances on cyclical fluctuations. Instead, the Australian case points to the origins of shocks and channels of transmission already mentioned (asset prices and imports of capital goods) as the driving forces behind the synchronization of activity with the rest of the world. Similar results are also obtained for Canada, in addition to the exports channel, to further support this view.

The findings of the last paragraph are of prime importance for theoretical work in this area of research. Equity markets and trade in capital goods have been omitted from NOEM models. As a result, empirical frameworks in this vein have neglected a crucial source and propagation mechanism of foreign shocks. Consequently, this study suggests that the inclusion of foreign capital in NOEM models represents a promising and worthy extension, which may also potentially result in dynamic responses more in line with the delays in response to the shocks observed in the empirical analysis. In addition, exploring the implications of synchronized equity markets for firms' financing in small open economies is another promising area for further research in this literature.

The paper is structured as follows. Section 2, introduces the dynamic factor framework and briefly compares it with other empirical work in this field. To make the paper self contained, the model and assumptions are laid out in this section. Details on the estimation using Markov Chain Monte Carlo methods, a discussion of model selection techniques together with some additional technical issues, have been omitted here and are included in Justiniano (2002). Nonetheless, several pages are required before arriving at the results. Data sources and the construction of the foreign aggregates are given in section 3. With the framework and data laid out, the theoretical impulse responses obtained with the model of McCallum and Nelson are discussed in section 4. In section 5, empirical impulse responses to the identified foreign factors obtained with the model from section 2 are presented by country. The origins and transmission mechanisms of foreign disturbances suggested by the data are presented. Moreover, the contrast between empirical and theoretical responses, as well as the implications of these findings for the theory, in particular with respect to the role of international linkages in investment, are also included here. Conclusions and suggestions for future research complete the paper in section 6.

2. Empirical Frameworks

This section begins with a brief review of studies using open economy SVARs and factor models in Australia and Canada. The main focus of this initial discussion revolves on the limitations of these methods for a comprehensive investigation of the roots and propagation of foreign shocks into these economies. A description of the main advantages of the model in this study precedes the introduction of the dynamic factor framework. Once the basic equations of the model are laid out, a discussion of its normalizing and identifying assumptions follows. A simple example is presented to illustrate the normalization and identification assumptions in the model. As already mentioned, only a very succinct reference is made to the estimation and model selection methods used, and the interested reader is referred to Justiniano (2002) for further details.

2.1. SVARS and Factor Models

Empirical work on cross-country interdependencies in economic activity, beyond simple correlations, has focused on SVARs and static factor models. SVARs have been extensively used in closed economy macroeconomics and to a substantially lesser degree for the open economy case.[9] This discrepancy is largely explained by the identifying assumptions needed to recover structural disturbances which, in the latter case, are not as clear-cut and widely accepted as for closed economies.[10]

Schmitt-Grohé (1998), Cushman and Zha (1996) and Burbridge and Harrion (1985) estimate SVARs and address the cofluctuations between Canada and the US. The picture that emerges from these three papers reveals that developments in the US, both real and monetary, have

[9] In addition to the references here, see Kwak (1998) for a VAR study on the origin of shocks.

[10] This said however, there is growing skepticism on the use of standard identifying assumptions, such as Cholelsky decompositions, in SVAR analysis. The discussion by Canova and Pina (1996) and Uhlig (1999) are clear examples. The way in which identification of the primitive disturbances is eventually achieved in these papers is closely related to the normalization and identification restrictions imposed in the factor model introduced below. Indeed, they are both aimed at fixing a matrix of orthonormal rotations to recover the underlying shocks. If anything, it is possible to argue that the particular normalization and identification assumptions adopted in this paper are more transparent to the reader than some of the methods that have been recently proposed in SVARs.

strong influences on real activity and nominal variables in Canada.

Pagan and Dungy (2000) propose a SVAR to explicitly address the effects of shocks to US variables (output, interest rates, share prices) on Australia. Their findings confirm that disturbances originating abroad play a pivotal role in accounting for fluctuations on Australian output.

A problem with SVARs is the loss of degrees of freedom as more variables are added, which renders them not suitable for studying large econometric models including several series. This dimensionality constraint becomes particularly binding when, in light of the various theories available, an agnostic approach to the sources and propagation of foreign fluctuations suggests using large datasets. Moreover, as the system is expanded, the number of restrictions needed to achieve identification grows quadratically.

Factor models in principle do not suffer from dimensionality restrictions as do SVARs.[11] The factor methodology permits the extraction of unobserved components common to a potentially large number of variables, that is, the factors. These framework have been applied, therefore, to determine if there is a shock to GDP responsible for the synchronization of business cycles across various countries.[12] Research in this area has further concluded that there are strong linkages in output amongst several economies, including Australia and Canada, although the magnitude of these comovements varies from one study to another.

When a geographic disaggregation (e.g., foreign vs. domestic) is intended for the factors, maximum likelihood estimation has, nonetheless, constrained the number of series that can be analyzed.[13] As a result, factor models to investigate cofluctuations usually focus on a few variables (output and, maybe, consumption and investment) observed, however, in a large number of countries.

Even when estimation hurdles are overcome, such as in Kose et al. (1998), dynamics in factor models are introduced under strong restrictions: mainly that series specific responses to the factors occur only contemporaneously. Dynamics are instead driven by autoregressions in the factors themselves. Given that the factors feed into all variables, then no heterogeneity in dynamics across series is, therefore, permitted in these setups.[14]

[11] See Gianonne et al. (2002) for a discussion of these and other advantages of factor models over SVARs.

[12] See for instance Bowden and Martin (1996), Lumsdaine and Prasad (1997) and Malek-Mansur (1999).

[13] Gregory et al. (1997). As discussed in Justiniano (2002), spectral methods are not well suited for these cases, when, in order to achieve a dichotomy in the factors, restrictions must be imposed in the way these affect subgroups of variables.

[14] The difference between series-specific dynamics as opposed to dynamics in the factors themselves, will be better appreciated once the model has been introduced in section 2.3. See footnote 17.

Since only contemporaneous effects are considered, no attempt is made to study impulse responses. Thereafter, while improving the analysis in one direction (a better characterization of the rest of the world by expanding the panel in the cross country dimension), it is not surprising that the factors methodology has, so far, been silent on any structural interpretation of the factors. In the end, these models provide an improved quantitative assessment of the magnitude of foreign shocks but do not deepen our understanding on either the sources or the transmission mechanisms of these disturbances.

2.2. An Alternative Dynamic Factor Analysis

2.2.1. Extending the framework

In order to address the origins and propagation of foreign shocks, the econometric methodology must expand the empirical framework to account for the shortcomings of SVARs and the type of factor models that have been applied so far. Consequently, the dynamic factor analysis of this paper adopts a framework with four key improvements over other studies: a) the inclusion of a large number of series for each country b) the introduction of less restrictive dynamics, from where c) the computation of impulse responses is used to suggest a structural interpretation of the factors and finally, d) the estimation of the model by Gibbs sampling, which can handle the high dimensionality of the parameter space and moreover, easily accommodates restrictions in the coefficients.[15][16]

First, this paper expands the number of series that are analyzed for each country, beyond just output and a handful of other variables as it has been customary in studies in international macroeconomics which rely on factor analysis. Given the ambiguities surrounding the origins and propagation of foreign shocks, enlarging the cross section in this dimension enables the researcher to simultaneously consider a large number of possible origins and transmission mechanisms of disturbances. Various theories for cofluctuations are consequently put to compete in a "horse race" to see which ones are best supported by the data.

Second, dynamics are introduced in a way appropriate for capturing differing lags in response to the same factor across variables. This feature of the model is of particular significance when

[15] Kaufmann (2000) also applies a dynamic factor model with these characteristics to the analysis of business cycles in industrialized countries. An earlier model in this vein, also not applied to an open economy setting, is Quah and Sargent (1993).

[16] This paper is thereafter closely related to the work of Kose et al. However the framework here improves their model in all but the third of the four dimensions emphasized. Shortcomings of this paper compared to theirs lie in the aggregation of series for the foreign block (see section 3) and the exclusion of a regional factor. Based on their results, the latter omission seems nonetheless to be of little relevance -at least- for Australia and Canada (once the US is included in the foreign block of the latter).

several series are considered given that there is no reason to believe that they will all react contemporaneously to the factors. Domestic goods prices, given price-stickiness, for instance, may not respond with the same speed to foreign disturbances as would the exchange rate or equity prices.

Third, as in the work of Malek-Mansur (1999), the framework of this study introduces dynamics in a way which facilitates the estimation of impulse responses for all series. By analyzing the response of all variables to the factors, it is possible to elucidate the origin of the underlying foreign shocks as well as to pinpoint the domestic series through which the disturbances are being channeled into Canada and Australia. As a result, this paper suggests a structural interpretation of the factors. With regards to point made in the previous paragraph, as shown later, estimated impulse responses display substantial heterogeneity in the delays in response to the factors, hence further validating the specification of dynamics proposed.

Finally, the Markov Chain Monte Carlo (MCMC) method used for inference, Gibbs sampling, is flexible enough to accommodate the inclusion of restrictions in the coefficients which permit the identification of the common components as corresponding to either foreign or domestic factors. In addition, Gibbs sampling overcomes dimensionality restrictions which have, due to laborious estimation methods, limited the scope of the analysis in other in other studies. Moreover, the MCMC algorithm of this paper easily provides a measure of uncertainty for the estimates.

The next section briefly introduces the dynamic factor model and discusses normalization and identification assumptions imposed for inferring the different components driving cofluctuations in the data.

2.3. The Model

Given a set of N series, indexed by i, demeaned and standardized, observed at every point in time, t, these are divided according to foreign and domestic variables. There are a total of N_f foreign and N_d domestic variables such that $N = N_f + N_d$. Each of the N series can be expressed as the sum of two orthogonal sets of components: the factors, denoted by F, that are common to all series, and the idiosyncratic errors, labeled ξ^i, which are specific to each variable and, therefore, indexed by the same series-superscript i. A total of K orthogonal factors, where K is substantially smaller than N ($K \ll N$), are to be inferred and are further subdivided into K_f foreign and K_d domestic factors ($K = K_f + K_d$). The distinction between domestic and foreign will be made explicit below when identification assumptions are introduced.

In the meantime, and more formally, with matrix and vector dimensions given as subscripts, $_{[m\times n]}$ indicating rows (m) and columns (n), let $y^i(t)$ denote an observation at time $t = 1, ..., T$ for any series $1 \leq i \leq N$, which can be written as

$$y^i(t) = B^i(L)F(t) + \xi^i(t) \tag{2.1}$$

where $F(t)_{[K\times 1]} = \begin{pmatrix} f^1(t) & f^2(t) & ... & f^K(t) \end{pmatrix}'$ is the column vector of factors, with f^j denoting the $j-$th factor. $\xi^i(t)$ represents the idiosyncratic error of y^i at time t. $B^i_{[1\times K]}(L)$ is a row vector of one sided lag polynomials of factor loadings (the coefficients on the factors) in the non-negative powers of L, and of order P:

$$B^i_{[1\times K]}(L) = \begin{pmatrix} B^{i,1}(L) & B^{i,2}(L) & ... & B^{i,K}(L) \end{pmatrix} \tag{2.2}$$

For ease of notation let the vector of loadings on series i for all factors at lag s, be given by

$$B^i_{s[1\times K]} = \begin{pmatrix} B^{i,1}_s & B^{i,2}_s & ... & B^{i,K}_s \end{pmatrix} \tag{2.3}$$

such that the $[B^{i,j}_s]$ element of B_s, represents the coefficient of factor $j = 1, .., K$ on series $i = 1, .., N$ at lag $s = 0, .., P$.

Expanding the lag polynomials in (2.2) and grouping the resulting terms by lag using (2.3), an alternative expression for (2.1) can be found which is used in the remainder of the paper:

$$y^i(t) = B^i_0F(t) + B^i_1F(t-1) + .. + B^i_PF(t-P) + \xi^i(t) \tag{2.4}$$

In addition to the dynamics in the factor loadings, the idiosyncratic disturbances are assumed to follow independent autoregressive processes of order Q, such that for $1 \leq i \leq N$

$$[1 - \phi^i(L)]\xi^i(t) = \eta^i(t) \tag{2.5}$$

η^i is a finite variance stationary, serially uncorrelated process, with all roots of $[1 - \Phi^i_Q(L)]$ outside the unit circle.

Equations (2.4) and (2.5) constitute the dynamic factor model for each series Notice that the factors are shocks whose effects on series y^i are traced out by the factor loadings. As mentioned, the factor loadings are series specific at all lags and, therefore, short run dynamics are fairly unrestricted.

One caveat of the current set up is, however, that it is not well suited for analyzing the long run fluctuations of the data, given that the effects of the factors die out after P periods.[17] Although the model and estimation technique can accommodate for non-stationary series, in this study the variables are first differenced or detrended to prevent the presence of very persistent components which would be attributed, thereafter, to the idiosyncratic error.

It might seem tempting to expand the model by adding an autoregressive structure in the factors. However, the presence of common roots in the autoregressive polynomials and factor loadings could result in non-identified models.[18] This extension is, therefore, not pursued in this paper.

Finally, within the factors literature, studies dealing with a large number of series usually first difference or detrend the data, without accounting for any possible common stochastic trends. This is, perhaps, a shortcoming of all studies using factors in rich cross sections to which this paper is no exception. In its current specification, the model presented here could allow for integrated series, as said, but cannot accommodate for the presence of cointegrating relations within blocks of series (say output-consumption) or across domestic and foreign blocks (open interest rate or purchasing power parity), which represents a potential weakness of the current setup. Extending the model to include the possibility of cointegration amongst series merits, therefore, further consideration.[19]

2.4. Normalization and Identification Assumptions

In order to identify the separate components (domestic and foreign factors, idiosyncratic errors) and to preclude indeterminacies in the model, further assumptions are needed. To avoid confusions, a distinction will be made between *normalization* and *identification*. *Normalization* will refer to any additional structure imposed to avoid having two observationally equivalent models. *Identification* will denote other assumptions embedded in the normalized model to distinguish idiosyncratic disturbances from factors and, within the latter, between domestic and foreign

[17] In the factor models discussed in section 2.1, as well as in Stock and Watson (1991), only contemporaneous factor loadings are allowed for such that $y^i(t) = B_0^i F(t) + \xi^i(t)$. The factors instead follow independent autoregressions of order R, $[1 - \rho^{\cdot j}(L)]f^j(t) = \epsilon^j(t)$. Consequently, provided (as it is usually assumed) that the lag polynomials are invertible, $[1 - \rho^{\cdot j}(L)]^{-1} = \Psi^j(L) = 1 + \sum_{v=1}^{\infty} \Psi_v L^v$ becomes the new lag polynomial of factor loadings with $\epsilon^j(t)$ as the factor. Notice these polynomials are series specific only through the contemporaneous loading.

[18] This is analogous to the well-known problem of common roots in the AR and MA components of ARMA models.

[19] One particular concern is that the presence of cointegration in the system compromises the existence of an invertible MA representation for the series.

shocks.

To separate factors from idiosyncratic disturbances the following identifying assumptions, which are fairly standard in (exact)[20] factor analysis, are made

Assumptions 1

1. $\eta^i(t) \sim N(0,(\sigma_n^i)^2)$ and $\eta^i(t) \perp \eta^j(t)$ $\forall i,j = 1,...,N$ and $i \neq j$ (orthogonality of idiosyncratic errors)

2. $f^j(t) \sim .N(0,(\sigma_f^j)^2)$ and $f^j(t) \perp f^k(t)$ $\forall k,j = 1,....,K$ and $k \neq j$ (orthogonality of factors)

3. $\eta^i(t) \perp f^j(t)$ $\forall\, i = 1,...N$ and $j = 1,...,K$ (idiosyncratic errors orthogonal to factors)

These assumptions imply that all comovements across variables are attributed exclusively to a set of orthogonal factors. In addition, variance-covariance matrices for both factors and idiosyncratic disturbances are diagonal. Appendix I presents the model in stacked notation and the implications of assumptions 1 for the representation of the model.

The remaining set of restrictions for identification, as well as the normalizations, are imposed in the matrix of factor loadings, which in stacked form is given by

$$B_{[N\times K(P+1)]} = \left[\begin{array}{cccc} B_{0[N\times K]} & B_{1[N\times K]} & ... & B_{P[N\times K]} \end{array}\right] \tag{2.6}$$

where from eq. (2.3) $B'_{s[N\times K]} = (B_s^{1\prime}\;\; B_s^{2\prime} ...\; B_s^{N\prime})$, for $s = 0,...,P$.

In order to dichotomize factors as of domestic or foreign origin, additional identifying assumptions are needed. Given that both Australia and Canada can be considered as small open economies (relative to the countries constituting the foreign block), then one plausible identification scheme is to assume no feedback from the domestic factor to the foreign series. The validity of this assumption is strengthened when taking into account that series from the US, Japan and the United Kingdom, amongst others, are aggregated to form the foreign block for Australia, while US data is used for the foreign sector in Canada (section 3). Exclusion restrictions of this form resemble closely the exogeneity of "world" variables used to identify shocks in open economy SVARs. Ordering the K_f foreign factors first, followed by K_d domestic, these restrictions of no feedback are imposed in all lags of the factor loadings and take the form:

[20] The GDFM of Lippi et. al. (2001), as well as the framework of Stock and Watson (2000) weaken the assumption of no cross-correlation in the idiosyncratic disturbances. Factor frameworks in which these assumption is relaxed are referred to as approximate factor models.

Assumptions 2

$$B_s^{i,j} = 0 \ for \ i = 1, ..., N_f$$

$$j = K_{f+1}, ..., K \quad (K_d = K - K_f) \quad and \quad s = 0, ..., P.$$

where recall that the $[B_s^{i,j}]$ element of B_s, stands for the coefficient of factor $j = 1, .., K$ on series $i = 1, .., N$ at lag $s = 0, .., P$.

Normalizations are imposed to preclude the existence of two observationally equivalent models which the researcher cannot distinguish[21] and take the form of a triangular scheme imposed on the matrix of contemporaneous loadings B, such that B_0 can be partitioned as follows:

$$B_0 = \begin{bmatrix} B^A_{0[N_f \times K_f]} & 0_{[N_f \times K_d]} \\ B^B_{0[N_d \times K_f]} & B^C_{0[N_d \times K_d]} \end{bmatrix} \tag{2.7}$$

with $B^A_{0[N_f \times K_f]}$ and $B^C_{0[N_d \times K_d]}$lower triangular matrices with ones on the diagonal, in order to fix the sign and scale of the factors.[22]

2.4.1. A Simple Example

To further illustrate the set of normalizations and identification assumptions made, consider the following simple example, which, for future reference, illustrates the normalizations used for Canada and Australia. The foreign block is comprised of two variables: foreign GDP, denoted by y_f, that is ordered first, and foreign share prices, sp_f. Similarly, the domestic block contains domestic output, y_d, and investment, I_d,. Postponing a discussion on model selection until section 2.6, suppose that two foreign and one domestic factors are included in the analysis. For simplicity, further assume that the idiosyncratic errors are also i.i.d. shocks $(\xi^i = \eta^i, i = 1, .., 4)$ and that there is only one lag in the polynomial of the factor loadings $(P = 1)$.

Identification and normalization assumptions result in a model of the following form:

$$\begin{pmatrix} y_f(t) \\ sp_f(t) \\ y_d(t) \\ I_d(t) \end{pmatrix} = B_{[4\times 6]} \begin{pmatrix} F_{[3\times 1]}(t) \\ F_{[3\times 1]}(t-1) \end{pmatrix} + \begin{pmatrix} \eta_{y_f}(t) \\ \eta_{sp_f}(t) \\ \eta_{y_d}(t) \\ \eta_{I_d}(t) \end{pmatrix}$$

$$F_{[3\times 1]}(t) = \begin{pmatrix} f^1(t) & f^2(t) & f^3(t) \end{pmatrix}'$$

[21]Multiplying factor and loadings with an invertible matrix $P_{K\times K}$ results in two observationally equivalent models since $\widehat{B}\widehat{F} = (BP^{-1})PF = BF$.

[22]This is the "hierarchical" structure of Geweke and Shou (1996) and Aguilar and West (2000).

with f^1 and f^2 foreign factors and f^3 domestic. The matrix of factor loadings is given by

$$B_{[4\times 6]} = \left(\begin{array}{cc} B_{0[4\times 3]} & B_{1[4\times 3]} \end{array} \right) =$$

$$\begin{bmatrix} 1 & 0 & 0 & B_1^{y_f,1} & B_1^{y_f,2} & 0 \\ B_0^{sp_f,1} & 1 & 0 & B_1^{sp_f,1} & B_1^{sp_f,2} & 0 \\ B_0^{y_d,1} & B_0^{y_d,2} & 1 & B_1^{y_d,1} & B_1^{y_d,2} & B_1^{y_d,3} \\ B_0^{I_d,1} & B_0^{I_d,2} & B_0^{I_d,3} & B_1^{I_d,1} & B_1^{I_d,2} & B_1^{I_d,3} \end{bmatrix}$$

Normalizations correspond to the ones and zeros in the first 4x3 submatrix (B_0). The identification of foreign and domestic factors, meanwhile, is achieved by imposing no feedback from the domestic factor into the foreign block. These restrictions take the form of $B_1^{y_f,3} = B_1^{sp_f(t),2} = 0$ and account for the zeros in the last column on B.

In this example, the first factor is normalized as the set of all foreign shocks associated with a contemporaneous expansion in foreign GDP which results in cofluctuations with some -but not necessarily all- of the remaining variables in the model: sp_f, y_d and I_d. Disturbances to y_f, that do not imply comovements with any other series, are bunched in the idiosyncratic term, η_{y_f}.

Regarding the second factor, it is plausible that foreign share prices affect economic activity in the small open economies under study, through developments in equity markets which are not *contemporaneously* associated with commonalities in output. Swings in investor sentiment, for example, can affect the availability of foreign financing for firms in these (domestic) economies without any impact on foreign GDP within the quarter. This, in turn, can strongly influence firms' decisions on investment in capital goods, thereby suggesting investment linkages as a possible propagation mechanism of foreign disturbances. Therefore, the second factor in this example is normalized to represent all shocks to foreign share prices, exhibiting comovements with either both or at least one of the domestic variables, y_d and I_d, that have no impact effects on y_f within the quarter (although possibly at lags, since $B_1^{y_f,2}$ is unrestricted). Clearly, disturbances that do result in contemporaneous cofluctuations of sp_f and y_f are included in the first factor.

As this example illustrates, alternative orderings of the variables imply different interpretations of the factors. Indeed, the normalizations entail expressing the first series as a factor plus an idiosyncratic error, the second series as the sum of two factors plus an innovation, and so on. Although this may seem a weakness of the current setup, it is argued that it represents an objective and comprehensive approach to the question that defines the focus of this paper.

Normalizing the foreign factor with foreign GDP, as f^1 above, allows to infer linear combinations of *all* shocks to foreign output which result in cofluctuations with the remaining variables of the system. The factor per-se, does not allow, therefore, the identification of the particular type of disturbances responsible for fluctuations in foreign GDP and the comovements in the data (e.g. innovations to monetary or fiscal policy, technology shocks, etc.). Using factors with this normalization to infer the underlying disturbances, permits, as a result, the even consideration of all shocks.

In order, to understand, precisely, which sort of disturbances constitute the factors, this paper expands the panels by adding other variables (such as exports, imports, productivity, etc.). As a result, the analysis provides both a comprehensive examination of a number of shocks -hence theories analyzed-, as well as an objective stance taken without weighing a particular disturbance over others.

Diverse variable orderings, thereafter, permit investigating different questions. Placing world oil prices first, for example, would be appropriate in studying the *specific* effects of oil shocks in generating any comovements in the data. If there are no disturbances to oil shocks associated with cofluctuations with the series in the panels, then this would result in impulse responses not significantly different from zero and in most of the explanatory power for this series being attributed to the idiosyncratic disturbance. With the present normalization, with foreign GDP, if oil shocks (or any other series for that matter) are the main engine beyond international comovements, then this would be captured by the factor regardless of the ordering of world oil prices in the foreign block.

The second factor on the example above seeks to explain any disturbances to foreign equity markets which result in cofluctuations, *beyond those innovations already accounted for with the first factor*. As discussed at length in section 5, shocks in equity markets are seen to be a major source of disturbances leading to comovements across countries. This is true both with the agnostic normalization using foreign output discussed above as well as -when more than one factor is estimated- with a factor normalized using foreign share prices as in this example.

2.5. Estimation of Dynamic Factor Models

The large number of domestic and foreign series to be included in the cross section pose significant challenges in the estimation of parameters in highly dimensional spaces and have constrained previous studies looking at factors. When, as here, analytical solutions are intractable and the dimension of the model makes the maximization of the likelihood problematic, Markov Chain Monte Carlo (MCMC) simulation methods can be applied to approximate the posterior densities of the parameters of interest. Gibbs sampling, a particular class of MCMC simulation based algorithms, is particularly well suited for inference in dynamic factor setups.

For details on the estimation, elicitation of conjugate priors and the form of the posterior distributions in dynamic factor models, as well as for additional references, see Justiniano (op. cit.). In regards to this analysis, it is enough to point out that the Gibbs sampler approximates joint and marginal posteriors of the model's parameters by dividing the parameters in blocks and sampling iteratively from the conditional distributions (given all other parameters and the data). In the current framework, this involves considering four subsets of the parameter set, B (factor loadings), Σ_n (variance-covariance of the innovations to the idiosyncratic disturbances), Σ_F (variance-covariance of the factors), Θ (autoregressive parameters of the idiosyncratic shocks), in addition to the factors themselves, $F^T = \{F(1), F(2), ..., F(T)\}$ such that the subscript T stands for the whole sample of factors obtained with the Kalman filter.

With a chain consisting of a large number of simulations, inference on the parameters is based on functionals of the simulated draws: i.e. means or medians are used to approximate posterior means, while the percentiles of the sampled values can be used to construct confidence bands. When the chains have converged (an issue taken up in Justiniano), they provide an accurate characterization of the posterior distributions.[23]

2.6. Determining the Number of Factors

In contrast to other applications (e.g., forecasting) and estimation methods (e.g., principal components), selecting the number of factors is of prime importance here. From a purely statistical point of view, models with redundant factors are not identified in this framework since the uniqueness of the identification scheme adopted in section 2.3.2 requires the matrix of factor

[23] Without going into the details, it should be pointed out here that inference using simulated data as well as a battery of convergence diagnostics suggest the Gibbs sampler used in this paper provides a good approximation to the means of the posterior densities within a thousand or so iterations. See footnote 49.

loadings to be of full column rank (K).[24]

The recent literature on factor analysis and principal components has not provided a reliable testing procedure for selecting models with different number of factors, particularly in dynamic settings.[25] Further computational demands, coupled with the burdensome estimation of factor models per-se, has pushed many authors to disregard any consideration of the number of factors.

Extension of Bayesian methods from static factor analysis to dynamic models, as well as a discussion of frequentist practices to deal with uncertainty in the number of factors can be found in Justiniano (op. cit.). In that paper, simulations reveal that one particular method for selecting across models of different dimensions in the factors yields accurate results and should be considered by practitioners using factor analysis.

More specifically, consider the problem of selecting a model with k_f and k_d foreign and domestic factors respectively, M_{k_f,k_d} , from the set of all models, denoted Γ_M, which differ from one another only in the number of factors included. From a Bayesian perspective, this entails selecting the model with the highest posterior probability $p\left(M_{k_f,k_d}\,|Y^T\right)$(conditional that is on the whole history of observed data, denoted Y^T). In simulations, the Reversible Markov Chain Monte Carlo (RMCMC) method of Dellaportas et al. (1998) results in posterior probabilities that in most instances (roughly 90% of the time) heavily favor (posterior probability near one) the true underlying model.

For the countries included in this paper, posterior probabilities over models ranging from one foreign and one domestic factor to larger models, considering three of each set of factors, are given in Table 1.[26] As seen from the table, the data favors a model with just one foreign and two domestic factors for Australia. For Canada, instead, judging from the posterior probabilities, a model with two foreign and two domestic factors is better supported by the data.

Table 1. Posterior probabilities across models for Australia obtained with RMCMC methods

15,000 iterations per model and 20,0000 draws in the Metropolis-Hastings Step

[24]This is discussed in Geweke and Singleton (1980). Freitas-Lopes (2000) reports that in simulations models overparametrized in the number of factors result in multi-modalities in posterior distributions and therefore in problems with the convergence of the chains.

[25]An exception is the work of Bai and Ng (2000) who have suggested modified versions of the Akaike and BIC criterion for a particular class of dynamic models. For the setting here, however, these tests can be misleading.

[26]These methods can readily be used to allow the universe of models to differ in the dimension of the matrix of factor loadings not only due to the number of factors but also because of differing lag lengths in the loadings. Computational demands however do limit the dimension of the model space, from where this approach was not pursued in this paper. The lag length was selected instead by looking at impulse responses and proposing a cut off point when an arbitrary number of them became insignificant.

	1 domestic factor	2 domestic factors	3 domestic factors
1 foreign factor	0	0.952	0.048
2 foreign factors	0	0	0
3 foreign factors	0	0	0

Table 2. Posterior probabilities across models for Canada obtained with RMCMC methods

15,000 iterations per model and 20,0000 draws in the Metropolis-Hastings Step

	1 domestic factor	2 domestic factors	3 domestic factors
1 foreign factor	0	0.023	0.048
2 foreign factors	0	0.977	0
3 foreign factors	0	0	0

3. Data

3.1. Sources and Sample

The framework of section 3 is applied to the small open economies of Australia and Canada. Quarterly data covering the period between 1984:Q1 and 2000:Q4 for Australia, and from 1983:Q1 to 2000:Q4 for Canada were collected. Sample start dates roughly coincide with the movement from fixed to flexible exchange rates in Australia and the abandonment of monetary targeting in Canada.[27] Including a larger sample with both fixed and flexible exchange rates would have made it imperative to take into account the possibility of structural breaks since the relevance and transmission of foreign shocks to these economies could potentially depend on the exchange rate regime in place.[28]

Data for the most part were collected from the periodicals *Main Economic Indicators, Quarterly National Accounts*, *Monthly Statistics of International Trade & Foreign Direct Investment*, all published by the OECD. Whenever necessary, additional data were obtained from DataStream and/or each country's central bank and statistics office. A more thorough description is provided in Appendix II.1.

[27]Australia abandoned the peg of the AU$ in Novemember of 1984. Canada's exchange rate, meanwhile, has been floating since the abaondonment of Bretton Woods.

[28]Kouparitsas (1998) concludes, for instance, that the magnitude of common fluctuations in the US and the G7 countries increased dramatically in the post-Bretton Woods era. Recent re-interpretations of the history of exchange rates by some authors, suggest however that further work is needed before any conclusion can be reached in this respect. See Reinhart and Rogoff (2002) for a discussion.

3.2. Construction of the Foreign Block and Transformations

VAR studies on the sources and propagation of foreign disturbances have relied for the most part on US data alone to construct the foreign block. While this seems an accurate approximation for extracting the relevant foreign shocks for Canada, this might not necessarily be true Australia. Table 3 shows the shares of total exports (sum of imports plus exports) for each country with the US, Japan, United Kingdom, Korea, Italy and France (and Mexico for Canada). Japan, for instance, has a greater weight share in total Australian trade than the US, accounting for roughly 20% of total trade.

An alternative approach must be sought, therefore, to better capture what represents the appropriate "rest of the world" for these economies. This has been the focus of factor models discussed in 2.1 that enlarge the cross section by including a small set of series observed in numerous countries. In contrast, this paper expands the cross section in the number of different series rather than in the cross-country dimension.

Ideally, the researcher would want to write a model which allows for both, that is for a set of factors that feed into a diverse set of series observed for a vast number of economies. Unfortunately, this would be computationally too intense given current computer capacity. For this reason a simpler method must be used to proxy the foreign block. The construction of the "rest of the world" by aggregating variables from a small number of relevant (for each small open economy) large countries represents an attempt to account for this shortcoming, while expanding the analysis in the direction proposed.

This obviously raises the question of how to aggregate the series across countries. One way is to take the weights in Table 3 and divide them by the total trade share accounted for with all countries listed (last line of the table) in order to obtain weights which sum up to one. Weights obtained in this manner are shown in the second column for each country in Table 3 (for the case of Canada, this aggregation procedure makes no difference in the results, given the predominance of the US, therefore, in section 5 results based solely on US data are presented).

Evidence on trade in goods as the main channel for generating cross-country linkages in economic activity is still a matter of controversy[29]. Thereafter, data on trade in financial assets is also used to obtain the weights for the construction of the foreign block, as described in Table 4. Data limitations (either due to availability or confidentiality restrictions) only permit

[29] Imbs(2000), for instance, casts doubts on trade shares being able to account for cofluctuations, while Canova and Dellas find a moderate role for trade in goods in explaining comovements in output. For a discussion in support of the trade channel see Kose and Yi (2002).

to use annual series on inward and outward positions on foreign direct investment to this end[30]. Results presented below are by and in large insensitive to the choice of weights, from where those corresponding only to total trade in goods are included in the paper.

Series from all countries in the foreign block were rebased to 1982:1, usually logged and added to form a levels aggregate. As expected, ADF-GLS unit root tests failed to reject the null hypothesis of non-stationarity for most series (both domestic and foreign) in the panel.[31] It is well known that these tests (even if close to optimal) have low power against local alternatives. In addition, several practitioners report that alternative detrending procedures can alter the properties of cyclical fluctuations and cross-country comovements. As a result, series were arbitrarily either first differenced or detrended using a quadratic trend. Appendix II.2 provides additional details.

Furthermore, in order to avoid analyzing cofluctuations which could arise simply from seasonal patterns, the data were seasonally adjusted. Whether to adjust or not was determined for each series (after aggregation for the foreign block) by inspection of the sample peridiogram at the seasonal frequencies ($\omega_j = 2\pi j/4$, $j = 1, 2$ for quarterly data).[32] If seasonal adjustment was deemed necessary, the X11 filter was applied. An alternative method for seasonal adjustment based on the inverse Fourier transform did not alter any of the results.[33]

4. A small open economy framework (McCallum and Nelson, 2001)

4.1. The theoretical framework

In order to illustrate the predictions of the theory, and as an aid in interpreting the impulse response functions to be estimated with the dynamic factor model, this section presents the micro-founded sticky-price framework of McCallum and Nelson (2001).

Given that the dynamic factor framework of this paper is more appropriate for studying short to medium-run responses to shocks, it is desirable to consider a model with an explicit role for monetary policy disturbances. Moreover, as mentioned in the introduction, interest in the

[30] Italy's and Korea's contribution becomes insignificant with this alternative weighting scheme, while the UK is attributed a larger weight for all three countries than when using trade in goods data.

[31] ADF-GLS unit root tests were proposed by Elliot et al. (1996).

[32] Tests for seasonality included in the X11 procedure in *E-views* were used to check wheather seasonal adjustment seemed necessary or not.

[33] To check the sensitivity of the results to the seasonal adjustment procedure, the series were alternatively adjusted by setting to zero the components of the sample peridiogram for a window of pi/64 around the seasonal frequencies. The inverse Fourier transform was then used to obtain the corresponding seasonally adjusted series. The results presented below are identical across procedures. For simplicity, those associated with the X11 are reported only.

sources and propagation of shocks also stems from policy considerations. This is particularly true for Canada and Australia, which during the 1990s adopted explicit inflation targeting regimes.[34] Within this framework for the conduct of policy, both countries have been concerned with achieving explicit target levels for inflation while at the same time stabilizing output.[35] For this reason, it is of prime importance for the monetary authority to understand the sources and transmission of foreign shocks, especially since different external disturbances might have similar effects on output but opposite implications for inflation.

Given all these reasons, a framework of the NOEM variety has been preferred. The particular choice, within this literature, of the model presented here merits, nonetheless, an additional discussion. Selecting a small open economy entails dealing with two unresolved issues in the NOEM literature: 1) the source of nominal rigidities and 2) the pricing practices of exporters and importers. Most NOEM papers focusing on small open economies have, however, assumed price, as opposed to wage, stickiness from where this first issue is not taken up here.[36]

Regarding the second point, assuming full pass-through of exchange rates to import/export prices or alternatively pricing to market practices (PTM) can have drastic effects on the transmission and welfare implications of monetary shocks.[37] Although providing an answer to this debate is far beyond the scope of this paper, the model taken here embraces the full pass-through assumption. Models with PTM alternative imply that a nominal depreciation of the currency results in improvements in the terms of trade (ratio of exports to imports prices).[38] As pointed out in Obstfeld and Rogoff (2001), however, for Australia and Canada (amongst other countries) terms of trade worsen with nominal depreciations which casts some doubts on the validity of PTM assumptions (at least for these economies).[39] Furthermore, the contemporaneous correla-

[34] For a discussion on the motivation and details on how policy has been conducted in these countries under inflation targeting see Bernanke et al (1999).

A theoretical exposition of inflation targeting in small open economies also can be found in Svensson (2000).

[35] *Flexible* inflation targeting in the terminology of Svensson (1999).

[36] An exception is Sutherland (2000).

[37] Two country models (large economies) assuming full pass through predict, for instance, negative cross-country output correlations and large positive correlations of consumption (as a result of expenditure switching effects caused by monetary shocks) which stand at odds with the data. In contrast, the framework of Betts and Devereux (2000) incorporates the assumption of PTM (owing to segmented international markets and local currency pricing practices) and explicitly accounts for this counter factual prediction of the theory.

[38] This is so given that if exporters keep prices fixed in the currency of the importer, then nominal exchange rate depreciations increase the domestic currency receipts of exports while leaving unchanged the domestic price of imports.

[39] Corsetti and Dedola (2002) propose a model that reconciles this relationship between terms of trade and the exchange rate in the presence of international price discrimination and incomplete pass through. Their model is a two country case and therefore not directly applicable to this paper. Their observations suggest nonetheless that an extension of their framework to the small open economy may be a fruitful research project.

tion of the log first difference of nominal effective exchange rates (an increase is an appreciation) and log first difference of import prices deflators, for the samples of this study, are –0.9 and –0.83 for Australia and Canada respectively.[40]

Within the class of models with full pass-through, the work of Galí and Monacelli (1999) has been cited -with good reason- as a canonical model for small open economies. McCallum and Nelson, have, nonetheless, criticized this framework, by looking at data from Canada and Australia amongst other countries, on grounds that it implies an excessive degree of influence of exchange rate changes on consumer price inflation. One way of reconciling the high degree of pass-through to import prices observed, with the small effect of currency changes on prices at the final goods level, is to treat the import good as an intermediate rather than a final consumption good. This assumption, as shown below, is one of the distinctive features of McCallum and Nelson's framework.

McCallum and Nelson look at a specific instance of policy in Australia and Canada (the Asian crisis of 1997) to support their claim that their model is better suited for describing inflation dynamics in these economies, represents an additional factor that influences the choice of the present model.[41] Finally, a key point is that McCallum and Nelson's framework allows for a variety of foreign and domestic shocks as opposed to only disturbances to labor productivity (and monetary policy) as in most small open economy models. Since this paper is concerned with the uncertainty surrounding the sources and propagation mechanisms of foreign shocks it is, therefore, better suited for the analysis and comparison of impulse responses for Australia and Canada.

In view of the above discussion, the log-linearized version of McCallum and Nelson's model is reproduced below for convenience:[42]

Fuhrer-Moore type Phillip's Curve

$$\pi_t = \phi E_t[\pi_{t+1}] + (1-\phi)(\pi_t) + \kappa(y_t - \widetilde{y}_t) \tag{4.1}$$

relating output y, potential output $\widetilde{y}$ and inflation π. $E_t[\cdot]$ denotes an expectational term based

[40] The work of Barucha et. al (2000) further suggests high pass through of exchange rate to imports for Australia. A recent paper by Obstfeld (2002) reaches similar conclusions for Canada and presents evidence to support the view that depreciations of the Canadian dollar vis-a-vis the US dollar increase the competitiveness of Canadian exports.

[41] In McCallum and Nelson's view, the low degree of pass through from exchange rate to CPI inflation helps explain why Australia's monetary response seems, ex-post, to have been more appropriate than the strong tightening observed in Canada during the Asian financial crisis.

[42] Notice that in this section variables are dated with subscripts $_t$ rather than (t). The latter notation was adopted in previous sections given the several indices that were needed for the factor loadings.

on information at time t.

Euler Equation[43]

$$c_t = E_t(c_t) - b_1[R_t - E_t(\pi_{t+1})] + v_t \tag{4.2}$$

for consumption c, with R the nominal interest rate and v a shock to household preferences[44]

Real exchange rate, q

$$q_t = s_t - p_t + p_t^* \tag{4.3}$$

where s is the nominal exchange rate while p and p^* denote domestic and foreign prices respectively. Note that an increase in s corresponds to a nominal depreciation, and similarly a rise in q denotes a real depreciation of the domestic currency.

Interest Parity

$$R_t = R_t^* + E_t[s_{t+1} - s_t] + \xi_t \tag{4.4}$$

R^* is then the foreign interest rate while ξ is a time varying risk premium

Import demand, m

$$m_t = y_t - \eta_{m,q} q_t \tag{4.5}$$

Export Demand, x

$$x_t = \eta_{x,y^*} y_t^* + \eta_{x,q} q_t \tag{4.6}$$

y^* is foreign output

Potential Output

$$\widetilde{y}_t = a_t - \varphi q_t \tag{4.7}$$

with a standing for a technology shock (labor productivity)

Taylor Rule (modified) [45]

$$R_t = (1 - \rho_R) R_{t-1} + \theta_{gap}(y_t - \widetilde{y}_t) + \theta_\pi \pi_t + er_t \tag{4.8}$$

er is the policy shock, and finally:

Economy's resource constraint

$$y_t = \omega_1 c_t + \omega_3 x_t - \omega_4 m_t \tag{4.9}$$

[43]In the original version of the model as well as in McCallum (2001), from where the baseline calibration is taken, the utility function accounts for habit formation. The Euler equation is therefore different to the one here presented.

[44]Stockman and Tesar (1995) have advocated including shocks to taste in IRBC models to better account for cofluctuations.

[45]In the callibration below presented, McCallum (01) replaces $y - \widetilde{y}$ with the expectation of this quantity at t-1.

Summarizing, there are four domestic domestic shocks in the model (a, v, er, ξ), corresponding respectively to innovations in labor productivity, monetary policy, household preferences and finally the exchange rate risk premium (this last one could also be considered as a foreign shock). In addition, three foreign shocks are included (y^*, p^*, R^*) standing respectively for disturbances to foreign output, prices and interest rates. These seven shocks drive the behavior of ten endogenous variables:[46]

$$(y, \widetilde{y}, \pi, c, R, p, s, q, x, m)$$

As discussed above, the full pass-through assumption implies that changes in real exchange rates induce expenditure switching effects. From (4.6) it follows that a real depreciation results in higher foreign demand for the small economy's goods. Moreover, the treatment of imports as intermediate goods implies that real exchange rate changes affect potential output (4.7) as well. A real depreciation increases the domestic currency cost of imports (4.5) leading to a decline in the economy's potential output.

Regarding inflation dynamics, a hybrid Phillip's curve is assumed, eq.(4.1), in order to impart greater inertia to the change in prices. Given that imports are not final goods, movements in the exchange rate do not directly influence final goods inflation but only through their impact on the output gap, through imports.

Finally, monetary policy is assumed to be well described by a Taylor type rule (4.9). No exchange rate term is included in this equation.

4.2. Responses to foreign output shock

Figure 4.1 presents impulse responses to a foreign output shock (y^*) computed for this model under the calibration proposed in McCallum (2002). In response to a positive innovation in foreign demand, the monetary authority raises interest rates to curb inflationary pressures given the expansion in GDP above potential output. Higher interest rates account for the appreciation of the real exchange rate and, thereafter, for the slight increase in potential output $(\widetilde{y})$.

The key prediction of interest for this paper is that cofluctuation (higher y^* and y) stems mostly from the strong positive response exports. Notice indeed from figure 4.1 that the direct demand effect (due to the increase in foreign output) dominates the expenditure switch away from domestic goods (real appreciation) and rationalizes the expansion in activity in the small open economy.

[46]The identity $\pi_t = p_t - p_{t-1}$ completes the model.

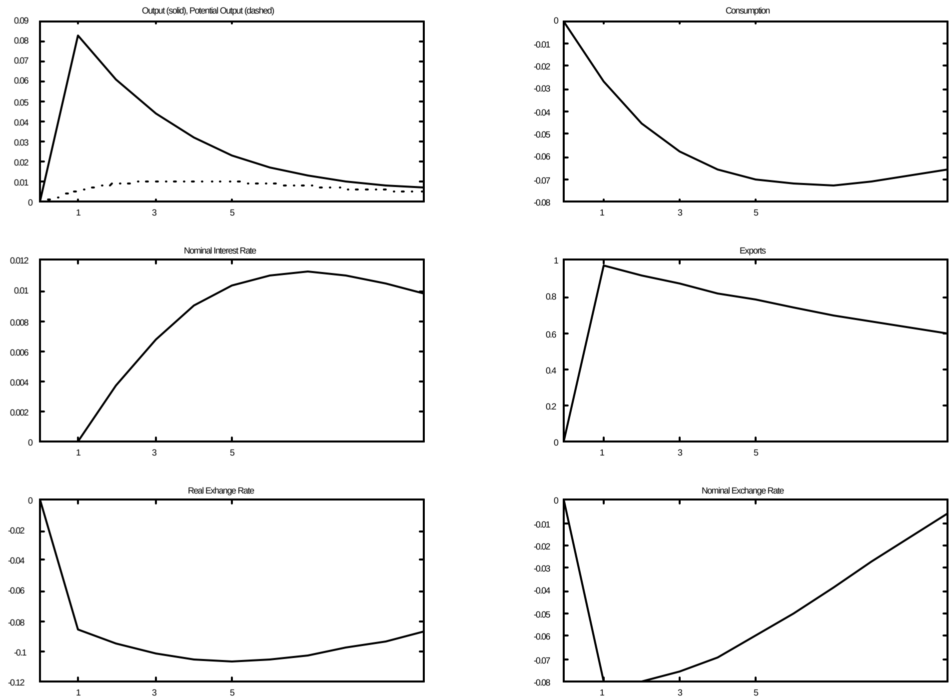

Figure 4.1: Impulse Responses to a 1% positive shock in foreign output. McCallum and Nelson (2001). Calibration follows McCallum (2002). Y-axis: % deviations from steady state.

Highlighting exports of final goods as the main transmitters of foreign disturbances, is not an exclusive feature of this particular framework but instead common to all small (and large) open economy models in the NOEM literature.[47] It was pointed out in the introduction, however, that despite its intuitive appeal, this channel of propagation could not account for the influence of foreign shocks in Australia.

To further test this assumption embedded in the NOEM literature it is necessary to infer an external output shock and analyze its effects on the domestic economy, as it was done here. The multi-factor framework of section 2 can be used to identify a positive output shock originating in the foreign block and to explore any possible cofluctuations with the domestic series. In this respect, notice that both the factors in example 2.4.1 and the analysis of the impulse responses in McCallum and Nelson's model do not imply the sources of the foreign output expansion (monetary, productivity shocks, etc.). The next section takes up these predictions for Canada and Australia but goes one step further in suggesting other sources of disturbances and

[47]In Galí and Monacelli (1999), a positive technology shock abroad also leads to a rise in foreign output and an appreciation of the currency given the reaction of the domestic Central Bank. Whether domestic and foreign output move in the same or opposite directions depends on which of two counteracting effects dominates (direct demand versus the negative expenditure switching).

transmission mechanisms.

5. Results from dynamic factors analysis

5.1. Canada

Recall from section 2 that RMCMC methods for model selection suggested estimating the model consisting of equations (2.4) and (2.5) with two foreign and two domestic factors for Canada. Moreover, bear in mind that, as discussed in the example in section 2.4.1, normalizing the first foreign factor with US GDP is intended to infer a linear combination of all innovations associated with a contemporaneous expansion in US GDP that can account for cofluctuations between Canada and the US.[48] In the current setup, this normalization represents the empirical counterpart to the shock analyzed in McCallum and Nelson's. That is, linear combination of shocks to foreign output are inferred, without any specific reference -at least initially- to the nature of these disturbances.[49]

Impulse responses to a one standard deviation of the factor are obtained by Gibbs sampling and presented in figures 5.1 and 5.2 These were computed from equation (2.4) by multiplying the factor loadings with the standard deviation of the corresponding factor. The dynamic factor model is estimated with 3 lags in the loadings, from where responses up to one year can be analyzed. For completeness, appendix III presents the stacked version of the model for Canada and makes explicit the normalization and identification assumptions, which parallel the discussion in example 2.4.1.

All series are (demeaned and) standardized for the estimation of the model. Once the coefficients of the impulse responses are inferred, however, each series is multiplied by its corresponding standard deviation in order to recover the original units. Consequently, impulse

[48]To readers unfamiliar with the factors methodology this normalization might seem cumbersome. It closely parallels, nonetheless, the use of simple bivariate VARs for isolating shocks to foreign output used in some studies of international business cycles. The added complexity lies, obviously, in analyzing these interactions for a large number of series.

[49]Chains of 30,000 draws are used, with the first 5000 draws discarded and 1 in every 5 remaining draws retained for inference, resulting in a sample of size 5000. The standard tests for convergence applied to the chains suggest that these provide an accurate characterization of the posterior target distributions, that is they have converged in a broad sense. Chains of shorter length result in identical characterization of medians and posterior percentiles. Serial correlation in the draws of impulse responses became statistically insignificant after 5 retained draws which strongly suggest the chains have mixed well. For the most part, with the exception of less than a dozen parameters, Geweke's (1991) relative numerical efficiencies are also well below 20 which is usually taken as an acceptable benchmark. The analysis of a random sample of the draws shows posterior distributions are unimodal and symmetric. In addition, the diagnostics of Raftery and Lewis (1992) (minimum runs, n-burns, suggested thinning parameter) corroborate the view that the chains provide an accurate characterization of the posterior distribution of the impulse responses.

Finally, principal component methods were used to derive starting values.

responses are interpreted as deviations from trend or quarterly changes -depending on the detrending method for each series- in percentage points, corresponding to a one standard deviation of the factor. Solid lines depict posterior medians while dotted lines represent the 15th and 85th percentiles of the joint posterior distribution of the loadings.

5.1.1. Exports and Productivity as Channels of Transmission

Figure 5.1 presents selected impulse responses for the United States, which constitutes the foreign block.[50] Given the normalization, it is not surprising that US GDP responds contemporaneously to the factor. A similar pattern is revealed by looking at the industrial production index. However, in this case, the deviations from trend last for all four quarters.

Disaggregating US output by expenditure, it is seen that consumption and investment also rise in response to the shock. For the latter, it is somewhat puzzling that contemporaneous effects become manifest, because presumably the cost of adjusting capital would result in delayed responses to the factors.

One possible source of the expansion in the US, could be a favorable labor productivity shock. This idea is further reinforced by noting that no significant inflationary pressures can be observed for the whole year after the initial rise in output (although the window of the analysis might be too short, given standard estimates of price-stickiness).[51]

One key observation is the marked response of the US imports series, which peaks with a one quarter delay. If cofluctuations are channeled through trade in goods, then presumably a concomitant expansion in Canadian exports would be observed. World mineral prices (labelled "W Mineral PI") and oil prices commove positively with US GDP, suggesting that the boost in aggregate demand should cause improvements in the terms of trade for countries exporting some of these commodities to the US.

Turning to the responses to this factor in Canada, in figure 5.2, several interesting findings emerge. In the first place, just as in the studies mentioned in section 2.1, Canada's GDP, industrial production index and unemployment rate (last subplot) reveal the existence of commonalities in economic activity with the US.[52] Figure 5.3 plots the factor inferred with the

[50]Recall that the list of all variables included in the model is given in appendix II.2

[51]This is a theoretical suggestion rather than an empirical observation. There is no consensus on how to measure output gaps, and a variety of methods to this end have been proposed. In some cases, a deviation from linear trend is taken as a measure of the gap, which would render erroneous the statement above made. In Appendix III a deviation from a quadratic (as opposed to linear) trend is used to estimate a Taylor type rule in Canada and to account somehow for possible breaks in potential output.

[52]It is interesting to notice the positive response of the Federal Funds rate *target* and its comovement with the Bank of Canada rate. Although this study by no means claims to have identified monetary policy, this

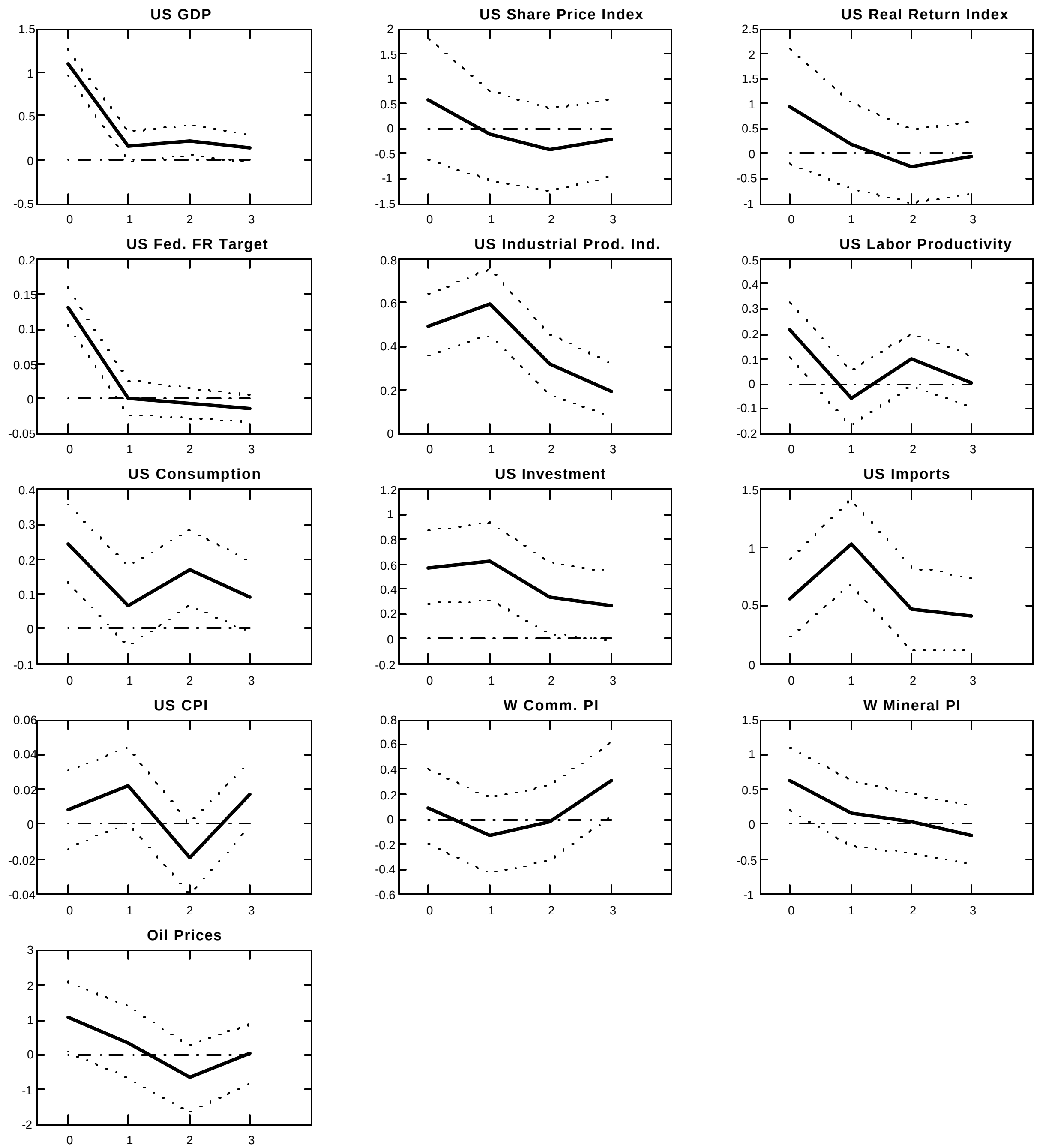

Figure 5.1: Impulse responses in the US to the factor normalized with a contemporaneous expansion in US output. Median (solid), 15th and 85th percentiles (dashed). 1 standard deviation innovation in the factor. Y-axis: % deviations from trend or quarterly changes.

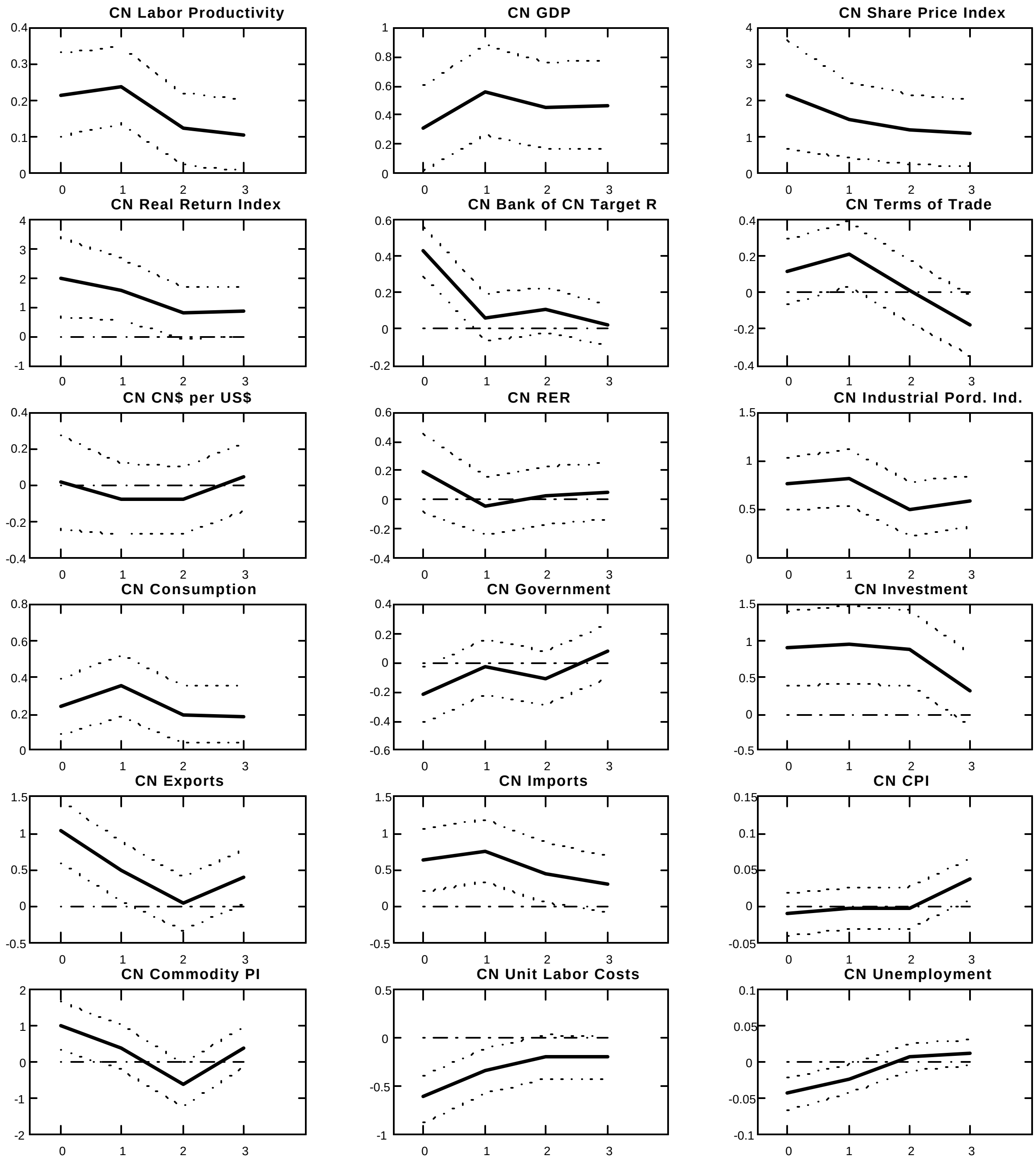

Figure 5.2: Impulse responses in Canada to the foreign factor normalized with a contemporaneous expansion in US output. Median (solid), 15th and 85th percentiles (dashed). 1 standard deviation innovation in the factor. Y-axis: % deviations from trend or quarterly rates of growth.

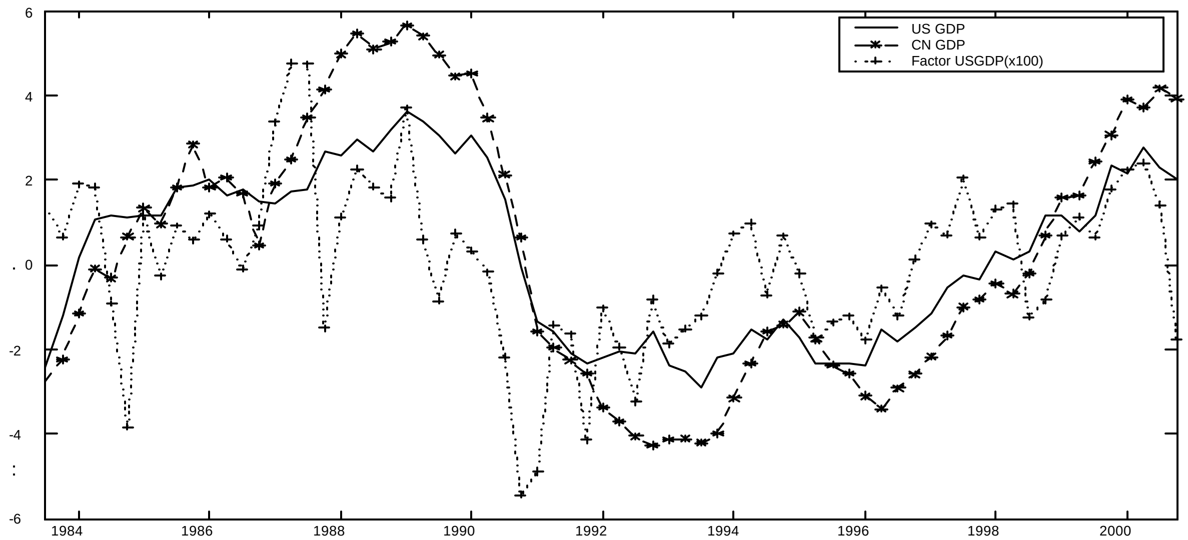

Figure 5.3: Foreign factor normalized with a contemporaneous expansion in US GDP, plotted together with GDP in Canada and the US. Output measured as log-deviation from trend, scaled by 100. Foreign factor corresponds to the median of the simulated values and is multiplied by 10 for comparison.

Gibbs sampler (scaled by 10) together with the log-deviations from trend in the US and Canadian GDP (multiplied by 100).[53] As observed, a common pattern of fluctuation dominates the three series, particularly between 1985-86, the dip in 1991 and especially from 1994 onwards. This last period suggests that the synchronization of comovements in these countries may have increased in recent years. There are, however, significant differences in the behavior of both outputs relative to the estimated factor in some instances, particularly at the end 1984 and in the period 1987-88. An interpretation of these discrepancies is offered below.

Returning to figure 5.2, labor productivity in Canada also exhibits positive cofluctuations with the same series in the US, which supports the view that productivity spillovers can account for comovements across countries. Positive innovations to productivity also explain the decline in unit labor costs (next-to-last subplot). One should keep in mind, however, that in this study productivity corresponds to labor productivity and does not, therefore, match Solow residuals constructed in the IRBC tradition.

The positive response of Canadian exports to the foreign factor represents one of the crucial

observation allows to speculate that the factor is to some degree capturing a tightening of the Fed in response to the underlying expansion in activity. Market rates, such as 90 day T-bills and 90 day Eurodollar rates (not shown) exhibit similar behavior. The Bank of Canada rate also shows a tightening of similar magnitude.

[53]The contemporaneous correlation coefficient of US and Canadian GDP with the factor is equal to 0.4 and 0.41, respectively.

observations of the present study.[54] This finding supports the standard assumption embedded in the NOEM, emphasized with McCallum and Nelson's model, that exports are a key mechanism for the transmission of foreign disturbances into small open economies.

The factor is also associated with a slight improvement in the terms of trade. This rise in the ratio of export to import prices is marginally significant, and occurs without any marked movement in the exchange rate, nominal or real. Therefore, it represents most likely an increase in the numerator, particularly given the positive response of world prices, rather than a decline in the denominator. The positive response of Canada's commodities price index also supports this view. In the next section, it will be emphasized that the observations for these two series, exports and terms of trade, contrast sharply with the results for Australia.

5.1.2. Investment, Imports and Equity Prices

Until now, the responses obtained with the factor model seem well in line with some of the broad implications of the IRBC and NOEM literature: productivity spillovers and trade in goods help account for output comovements. An important set of additional observations from figures 5.1 and 5.2 concerns the linkages between investment, imports and share prices.

The factor methodology highlights the presence of cofluctuations in investment between Canada and the United States, which help sustain the boom in output observed in both countries. This is especially true considering that deviations from trend in Canadian exports are not significantly different from zero from the second quarter onwards, while still positive and significant for output.

Moreover, roughly half of the total value of imports in Canada corresponds to machinery and transport equipment (Table 5). Therefore, it is reasonable to argue that, apart from any effects from private consumption, the observed expansion in imports is fueled by an increase in investment.

Concomitant with these developments, equity prices soar in Canada, which suggests analyzing if the observed fluctuations in investment are, to some extent, motivated by the effect of the foreign factor on the domestic equity market. Clearly, comovements in equity prices and investment do not necessarily suggest a causal relation from the former to the latter, or vice versa. The rise in Canadian share prices could well originate in the transmission of productivity shocks, with the consequent anticipation of higher future dividends rationalizing both rising

[54] The timing is somewhat hard to reconcile, especially since US imports peak with a delay, although the response of imports is still positive contemporaneously.

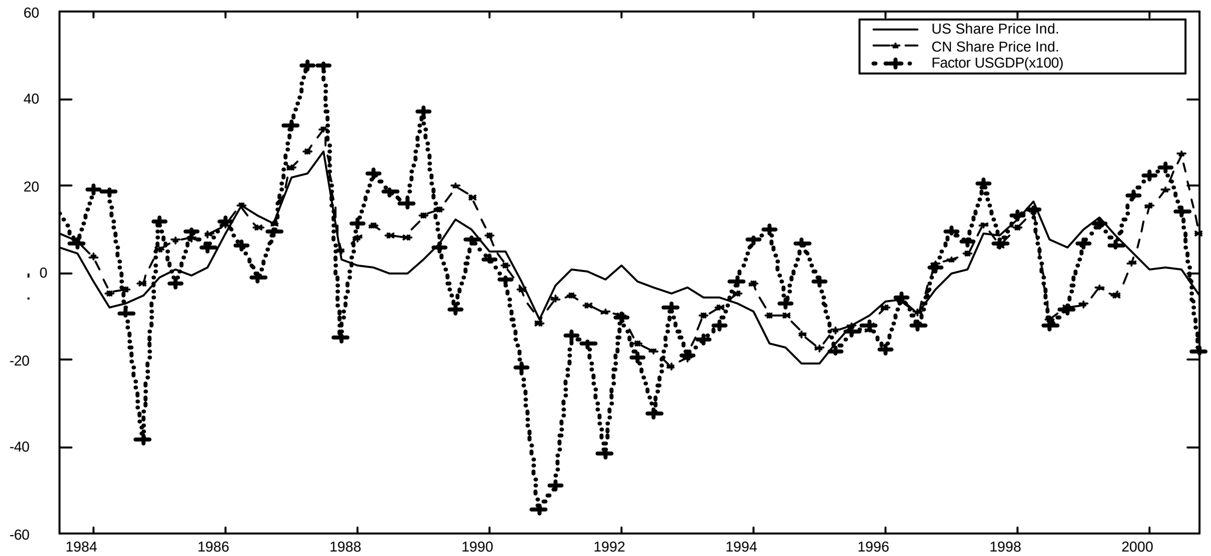

Figure 5.4: Foreign factor normalized with a contemporaneous expansion in US GDP, plotted together with share price indeces in Canada and the US. Share prices measured as log-deviation from trend, scaled by 100. Foreign factor corresponds to the median of the simulated values and is also multiplied by 100.

equity prices and additional investment by firms. An alternative view suggests that innovations to equity prices affect investment by impacting firms borrowing capacity (net worth), inducing changes in Tobin's Q or simply through anticipated changes in GDP (the flexible accelerator).[55] For Canada, there is evidence in support of positive innovations in equity prices inducing an expansion in output, which further implies that one or more of the channels mentioned in the last paragraph may be at play.[56]

The fact that the boom in equity prices originates in the foreign factor is central to the focus of the current paper. Although impulse responses do not show a significant positive response in US equity prices, figure 5.4 exposes the synchronization of stock return in the US and Canada. Particularly notorious is the collapse of both stock markets following the debacles in Wall Street at the end of 1987 and the run up of the mid 1990s, which are well captured by the factor.[57]

[55] A discussion, in a closed economy framework, of these effects of asset prices on investment, consumption and consequently the business cycle appears in Chapter 3 of the World Economic Outlook (2000).

[56] Goodhart and Hofmann (2001) identify shocks to equity and other asset prices in G7 countries using a SVAR. From their analysis they conclude that higher share prices are responsible for statistically significant positive responses in output for all countries in their sample, including Canada.

Moreover, the real return series in figure 5.2 coincides with crude measures of (average) Q used in some papers, from where the expansion in investment should not be surprising according to the Q theory of capital formation. See Obstfeld and Rogoff (1996) chapter 4 for a presentation of the Q-theory.

[57] The contemporaneous correlation between US and Canadian share prices and the factor equals 0.5 and 0.68, respectively.

To further pursue this idea, the share price index in the US is ordered below output in the foreign block for the estimation of the second factor.[58] Just as in example 2.4.1, the second foreign factor is, hence, normalized to represent all underlying shocks to US equity markets responsible for cofluctuations with Canada, and not associated with contemporaneous expansions in US GDP. This aims at separating, to some degree, the impact of US stock markets on the Canadian economy from the direct foreign demand effects (higher US output contemporaneously) with which movements in stock returns may be associated.

Figure 5.5 displays impulse responses under this normalization for the US. The factor induces a positive deviation from trend in labor productivity with a 4 quarter lag. The contemporaneous rise in share prices, and in particular real returns, is consistent with innovations responsible for embodied technical progress, the effects of which are reflected in today's share prices as discussed above. Notice, nonetheless, that investment responds before the actual shock to technology is realized.

For Canada, figure 5.6 now reveals a sharp response to the factor in equity prices and returns in that country. Figure 5.7, meanwhile, plots this second factor together with share price indices in the US and Canada and further implies a high degree of cofluctuation in these series.

There are no clear-cut effects on GDP, or other measures of activity as in the previous factor. Similar remarks hold for labor productivity, despite the marginally significant contemporaneous response. However, despite the absence of these effects, investment still cofluctuates with its US counterpart. Moreover, imports are once again observed to expand, with the peak in both imports and investment coinciding at 2 quarters after the shock.[59]

In addition, foreign positive innovations to domestic equity prices are also associated with rising private consumption. To the extent that households' net wealth includes holdings of equity, fluctuations in share prices will induce changes in consumption.[60] The equity-net wealth effect is potentially also at work in the first factor as well.

In summary, factor analysis reveals that shocks to US share prices and stock returns are associated with similar developments in Canada's equity markets, and that, moreover, these disturbances imply real effects. There is also clear evidence of commonalities in investment

[58]This was the ordering used in determining the number of factors.

[59]The terms of trade do not improve despite the large appreciation (nominal and real) of the currency in Canada. Contrary to the previous case, this factor is associated with declines in commodity prices in the rest of the world and Canada (as well as oil) from where the effects on the numerator and denominator in the terms of trade might be cancelling themselves out.

[60]World Economic Outlook (2000).

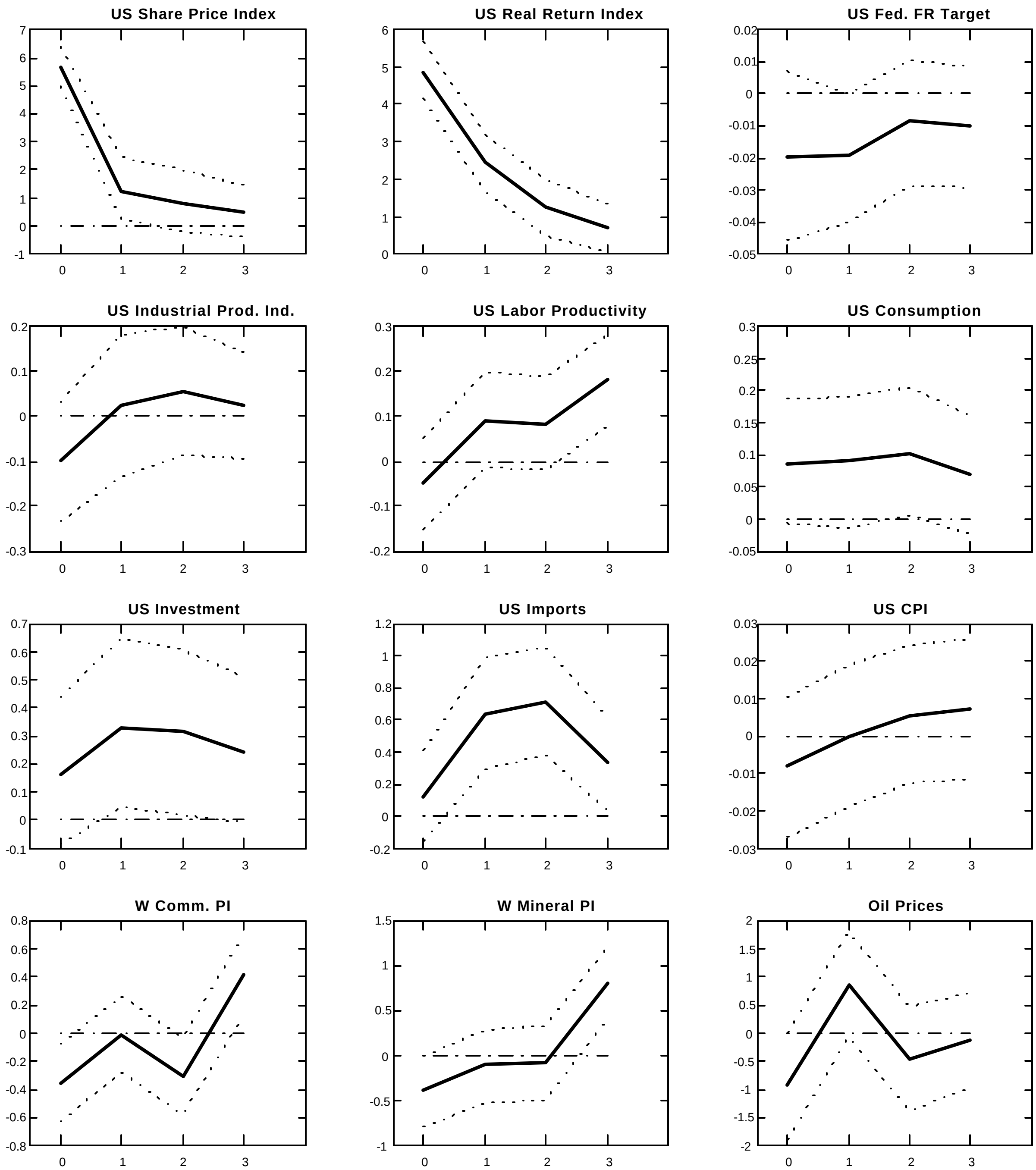

Figure 5.5: Impulse responses in the US to the foreign factor normalized with a contemporaneous expansion in US share prices. Median (solid), 15th and 85th percentiles (dashed). 1 standard deviation innovation in the factor. Y-axis: % deviations from trend or quarterly rates of growth.

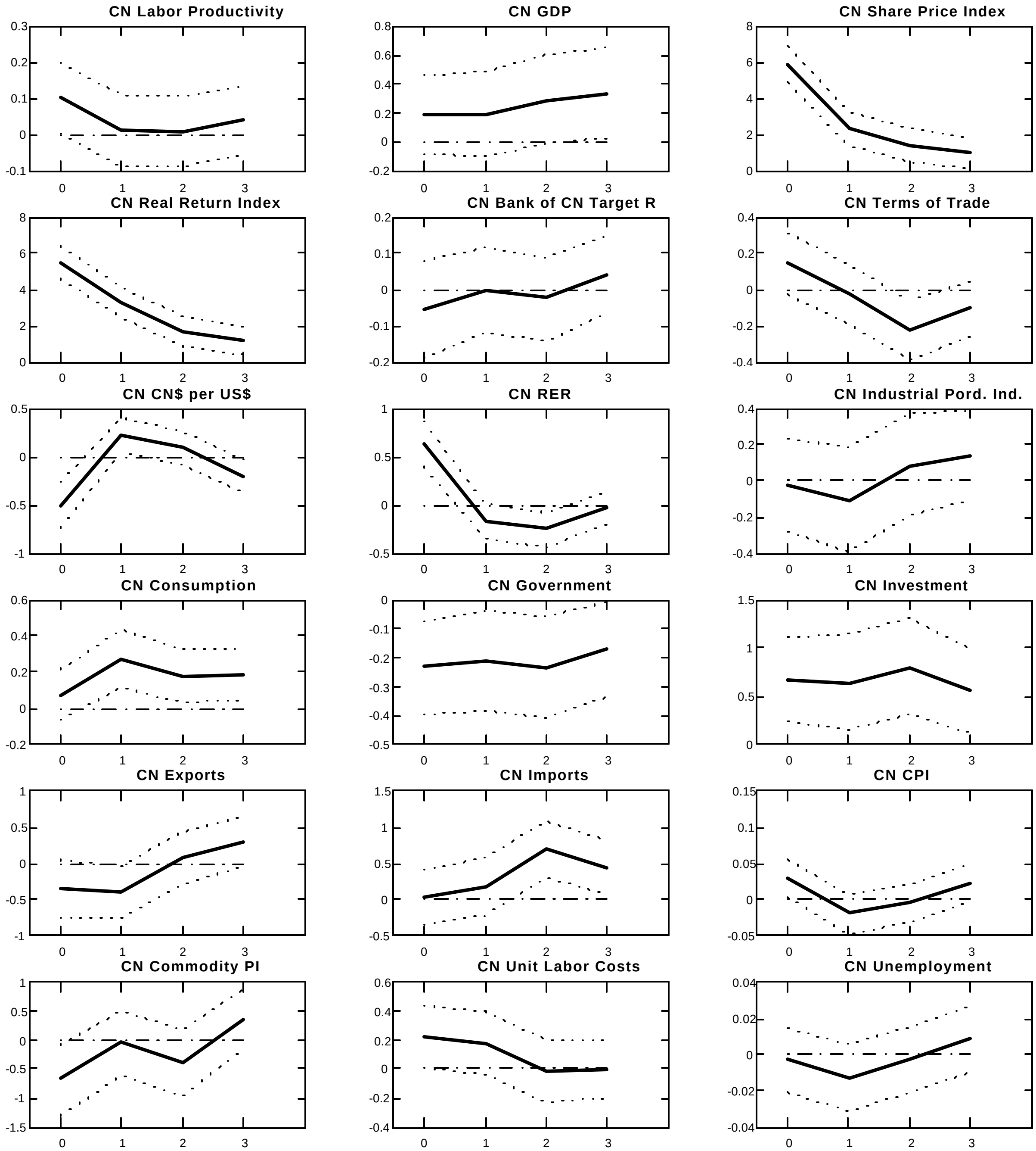

Figure 5.6: Impulse responses in Canada to the foreign factor normalized with a contemporaneous expansion in US share prices. Median (solid), 15th and 85th percentiles (dashed). 1 standard deviation innovation in the factor. Y-axis: % deviations from trend or quarterly rates of growth.

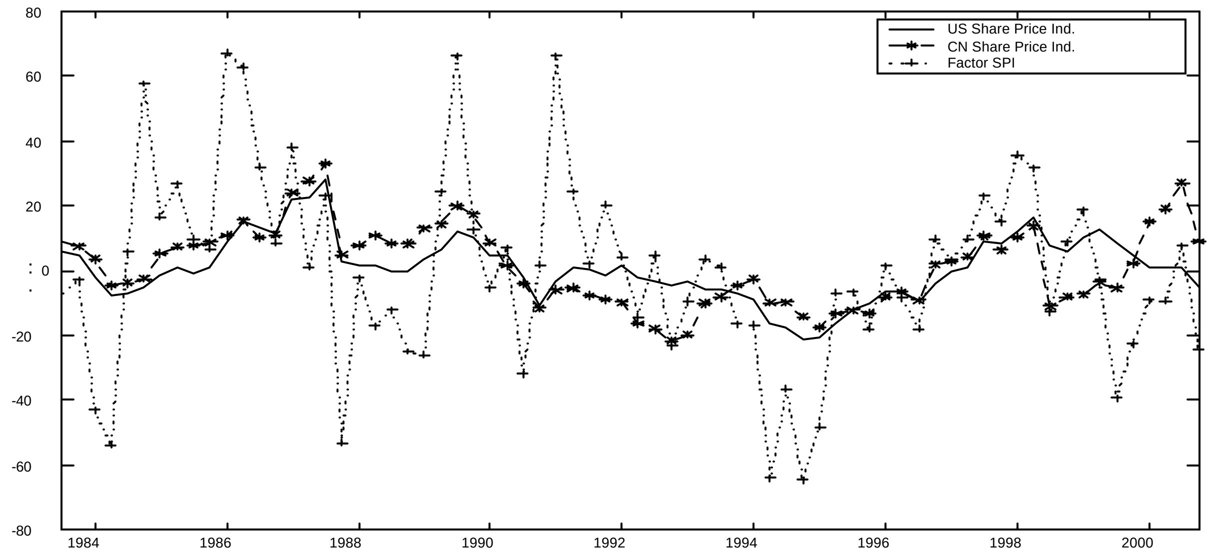

Figure 5.7: Foreign factor normalized with a contemporaneous expansion in US share prices, plotted together with share price indeces in Canada and the US. Share prices measured as log-deviation from trend, scaled by 100. Foreign factor corresponds to the median of the simulated values and is also multiplied by 100.

between these two countries, beyond those observed in output. In fact, investment plays a crucial role in the transmission of shocks originating abroad. Moreover, given the dependence on foreign capital, the response of investment in Canada is seen to be closely tied to that of imports. Further work needs to be done to understand -at a micro level- the exact underlying forces linking share prices to investment spending (e.g. effects on firms' net worth or expectations). Despite the fact that this paper does not test any particular theory in this regard, the results of this section are important because they reveal sources and propagation mechanisms of foreign shocks in Canada not highlighted by the NOEM literature.

5.2. Australia

5.2.1. Skepticism on Productivity Spillovers and the Puzzling Lack of Response in Exports

For Australia, model selection methods suggest estimating only one foreign and two domestic factors. Once again, just as in the Canadian case, the foreign factor is normalized with a contemporaneous increase in output abroad, which facilitates comparisons with the framework of McCallum and Nelson. As before, the units of the impulse responses for the Australian block corresponds to % deviations from trend or quarterly rates of growth in response to a one standard deviation innovation in the factor. For the foreign block, meanwhile, impulse responses are presented in factor standard deviations.

Figure 5.8 begins by looking at the responses to the factor in the foreign block, constructed by aggregating series from Japan, the US, France, Italy, Korea and the United Kingdom. The patterns of the impulse responses are, for the most part, similar to those obtained for the US with the same normalization when discussing Canada.

Mainly, expansions in foreign output and industrial production index are observed. The federal funds rate in the US, as well as an aggregate of market interest rates (not shown) also respond to the factor with positive changes. Foreign labor productivity and imports exhibit positive deviations from trend as well.

A fundamental difference, though, between the foreign factor in Canada and in Australia is that now sharp responses of both share prices and real return indices are observed. This was only true in Canada when normalizing a second factor.

Turning to the Australian block in figure 5.9, a number of interesting and somewhat surprising patterns of response to the foreign factor are noted. First, Australian GDP and, in particular the industrial production index, exhibit positive cofluctuations with their foreign counterparts, further reinforcing claims that foreign shocks influence Australia's cyclical fluctuations in activity. The response of both series occurs with a delay of two quarters. This observation indicates that the lag structure in the factor loadings adopted in this paper (as opposed to just contemporaneous coefficients) is quite relevant for capturing the role of foreign disturbances in this country.

In contrast to the Canadian case, the strength of these cofluctuations seems to be weaker. Figure 5.11 plots foreign and Australian GDP together with the factor. The graph supports the view that the comovements in output are not as marked as in Canada.

Second, despite the increases in foreign labor productivity, no similar response is observed for this series in Australia. Unfortunately, the lack of uniform data on capital stocks -for the countries and sample used to aggregate the foreign block- do not permit the construction of Solow residuals, and therefore, prevent reaching any definite conclusions on this matter. The findings of this study should, nonetheless, provoke some skepticism that productivity spillovers can account for fluctuations common to Australia and the foreign sector.

Third, one of the most striking findings of this analysis is that exports show a muted response to the foreign factor. Given that the Australian dollar strongly appreciates in real (and nominal) terms, it is possible that the expenditure switching effect could crowd out the direct

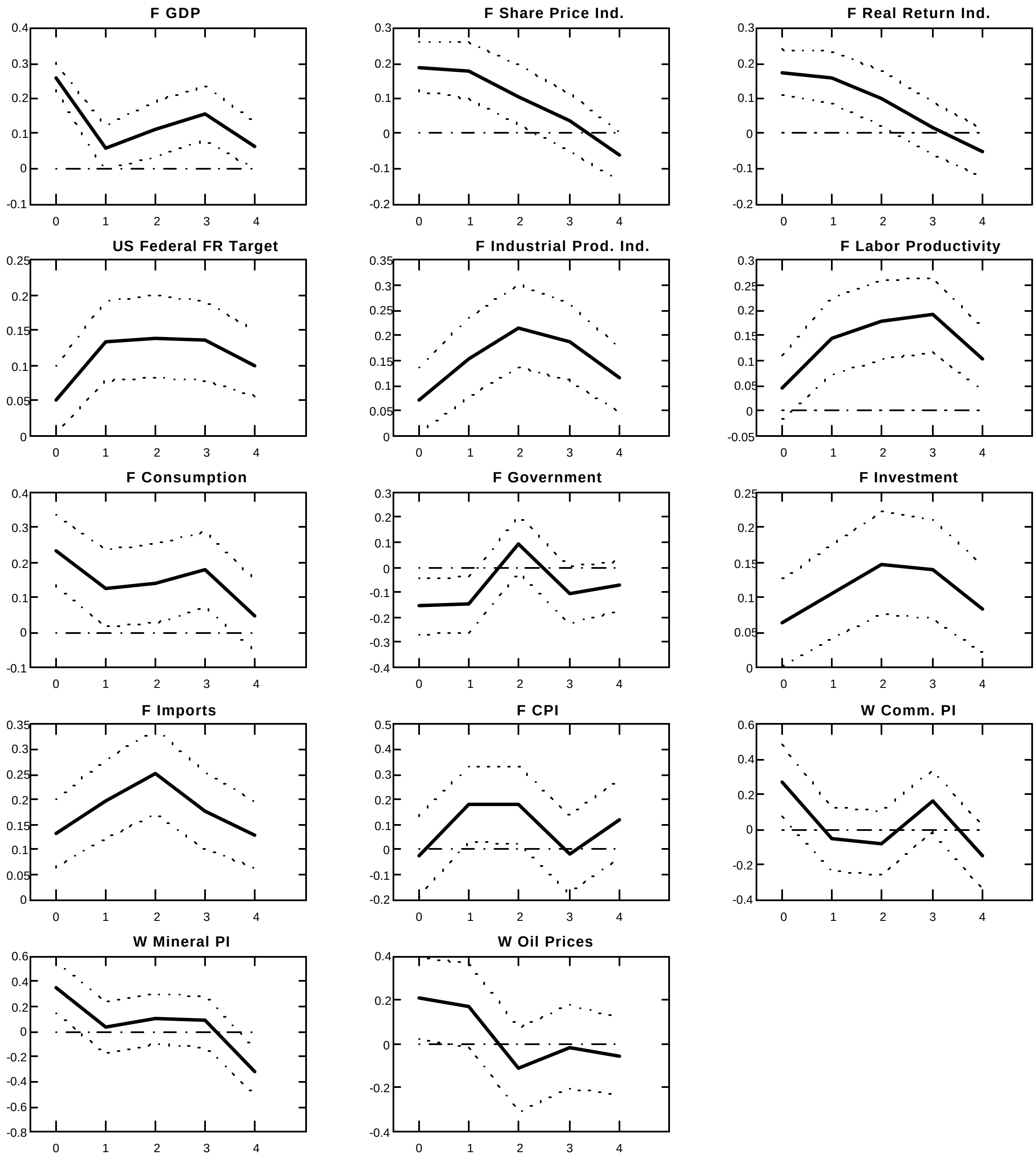

Figure 5.8: Impulse responses in the foreign block (hence series preceded by F) to the factor normalized with a contemporaneous expansion in foreign output. Median (solid), 15th and 85th percentiles (dashed). 1 standard deviation innovation in the factor. Due to the different scales resulting from aggregating series and using world prices, the impulse responses are measured in factor standard deviations.

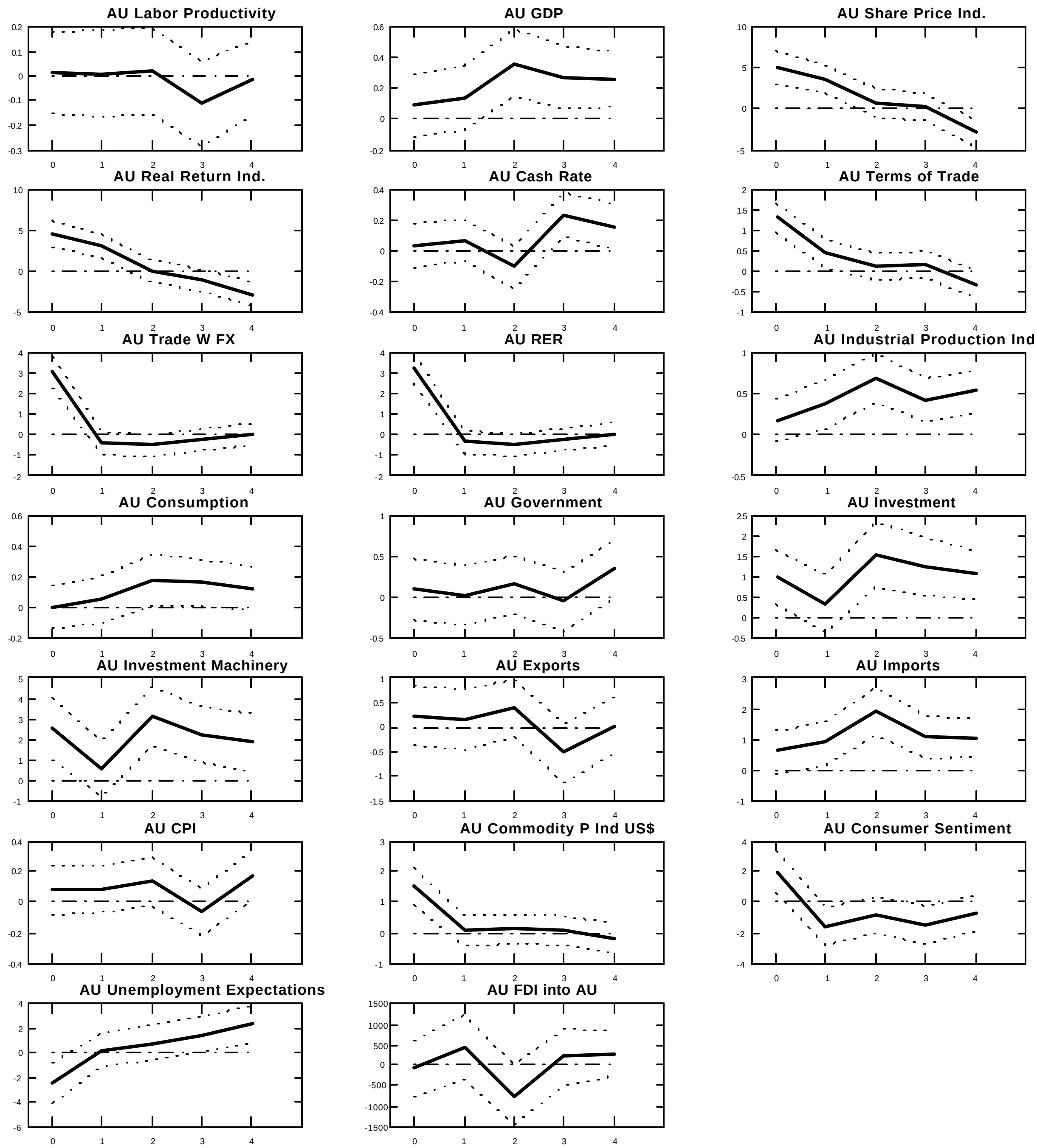

Figure 5.9: Impulse responses in Australia to the factor normalized with a contemporaneous expansion in foreign output. Median (solid), 15th and 85th percentiles (dashed). 1 standard deviation innovation in the factor. Y-axis: % deviations from trend or quarterly changes.

stimulus from a boom in output abroad. Therefore, that exports do not respond does not seem surprising. What proves to be puzzling, however, is that behavior of exports cannot explain how an expansion abroad translates eventually into a domestic increase in economic activity.

As previously mentioned, this finding is far from unique to this study or its econometric method. Researchers at the Reserve Bank of Australia have also been surprised when they have failed to establish a link between the behavior of Australian exports and foreign shocks.[61]

De Roos and Russell (1996) argue that Japan and the US have the highest output elasticity with respect to Australia's exports. As a result, they address the lack of response in exports found in other studies by building a foreign block comprised exclusively of data from these two countries.[62] In order to account for De Roos and Russell's observation, a new database was constructed by re-scaling the weights in table 3 to include only Japan and the United States. In this alternative characterization of the foreign block, the results for the foreign factor (not shown) were unchanged. Moreover, the foreign factor did not produce any significant rises (or declines) in exports even when disaggregated data on real exports was used to account for changes in the composition of Australia's foreign trade. Similar conclusions arise if using averages of monthly export volume indices.

5.2.2. McCallum and Nelson Reconsidered

From the results in the previous subsection, the dynamic factor analysis casts doubt on the view that productivity spillovers and exports can account for cofluctuations between Australia and the rest of the world. The lack of evidence is particularly robust for exports. While this study does not intend to claim that exports have no effect on Australia's GDP nor that they are insensitive to economic conditions abroad, the factors methodology suggests propagation mechanisms for the foreign disturbances other than through exports.

This last point challenges one of the main assumptions of NOEM models, as exemplified with McCallum and Nelson's framework. In addition, it stands in stark contrast with the results for Canada where exports were seen to explain, at least part of, US-Canada's interdependence rather well.

McCallum and Nelson's model is re-calibrated for the particulars of the Australian economy to ensure that the predictions of the theory do not stand at odds with the data simply from

[61] In addition to the reference in section 1, see Preston and Debelle (1995).

[62] In contrast to most studies, the authors obtain some significant and positive point estimates, for the coefficient on foreign output in single regression equations for exports. They acknowledge, nonetheless, that exports do not have large explanatory power on domestic activity.

failing to account for the conduct of policy or inflation dynamics in this country. In order to achieve this goal, the Phillips' curve (4.1) and the Taylor rule (4.8) are estimated using GMM and non-linear two stage least squares as described in Appendix IV. The remaining structural parameters for the calibration are chosen to match as best as possible the volatilities of most variables.

Details on the calibration are shown in Tables 6. Table 7 reports the theoretical variances obtained by simulating the model 100 times with samples of 75 observations. As seen in that table this particular framework does fairly well in replicating the variance of output and consumption. The fundamental purpose of this calibration exercise is to emphasize the implications regarding the transmission of foreign shocks obtained from the impulse responses, rather than to make any judgements on the model based on its ability to match the emprical standard deviations of the series. Nonetheless, it is interesting to observe that the model implies an excessive volatility of exports. In a similar manner, calibrating the model with a higher sensitivity of imports (e.q. 4.5) to the exchange rate - in comparison to McCallum and Nelson's calibration with $n_{x,q}$ equal to one- still under-predicts the volatility of imports.

McCallum and Nelson's model breaks the link between consumption and imports, because the latter are treated as intermediate rather than final goods. This simulation exercise, suggests that this is a desirable feature of their model given that, presumably, if imports represent only final goods then the volatility of imports will be tied to that of consumption. In this case, the model will either imply excessive volatility of consumption or further widen the gap between theoretical and empirical volatilities for imports. Moreover, the share of imports in Australia and Canada are seen to fall heavily on the production side, albeit in capital not intermediate goods. We shall return to this point briefly.

As seen in figure 5.10, the model's impulse responses with the calibrated parameters for Australia still predict large expansions in exports as the main engine behind the increase in domestic activity.

5.2.3. Sources and Propagation Mechanisms Revisited: Foreign Capital

Further scrutiny of the impulse responses to the foreign factor in figures 5.8 and 5.9 strongly suggests alternative sources of external disturbances and propagation mechanisms, other than exports, for Australia. In the first place, just as in the case of Canada, there is a strong link between imports and investment, with the peaks in these two series coinciding at a lag of two

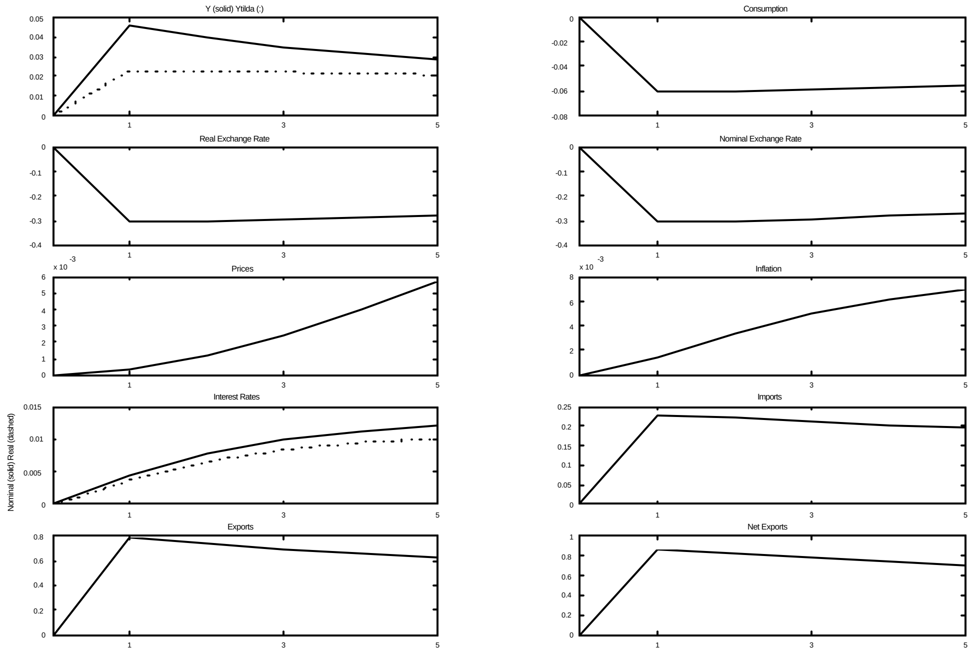

Figure 5.10: Impulse responses to a 1% upward shock in foreign output. McCallum and Nelson (01). Calibration for Australia as described in Table 6.1 and 6.2. Y-axis (% deviations from steady state).

quarters. Second, imports of machinery and transport equipment account for 42% of the value of goods purchased from abroad (Table 5), such that common fluctuations in this series are to be expected . Last, the positive impulse response of the series for investment in machinery included in the panel confirms this result (notice once again the coincident peaks with a two quarter delay).

For Australia, however, the improvement in the terms of trade plays a greater role than in Canada in fostering the boom in imports. Impulse responses in the foreign block imply positive responses of world prices to the expansion in economic activity abroad. This not only becomes manifest in commodity and mineral prices (a significant share of Australian exports is comprised of minerals, metals, lamb and wool) but also in the commodity price index published by the Reserve Bank of Australia (denominated in US$). In addition, as previously mentioned, there is a sharp appreciation of the Australian dollar which does not seem to stem from higher domestic interest rates. Given the high degree of pass-through from exchange rates to import prices, it is, therefore, not surprising that an expansion in imports becomes evident.

The next issue involves an exploration of any link between foreign disturbances, share prices and investment, by first highlighting the synchronization of fluctuations in share price indices

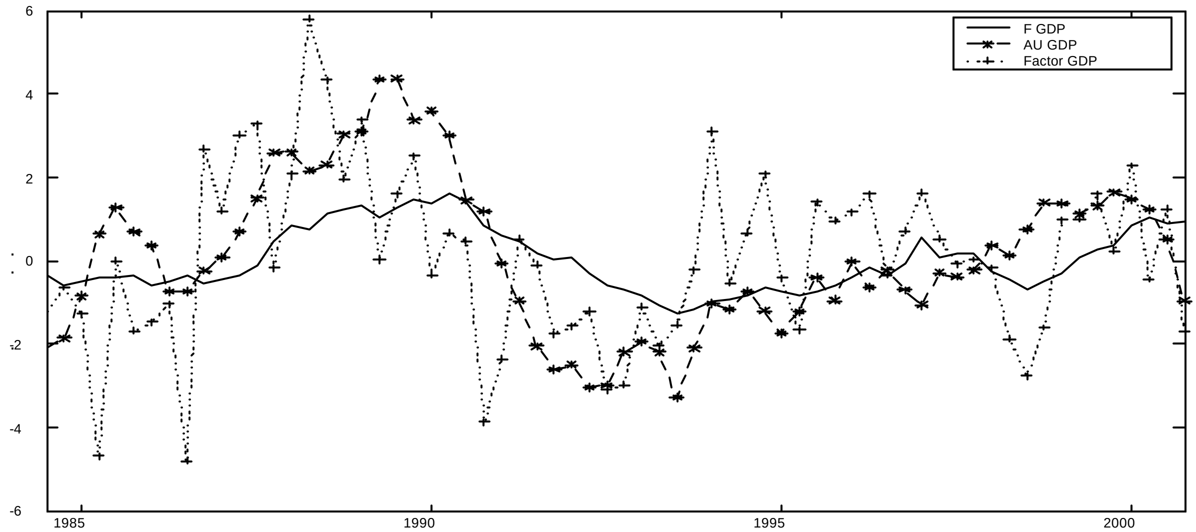

Figure 5.11: Foreign factor normalized with a contemporaneous expansion in foreign GDP, plotted together with foreign and Australian output, measured as log-deviation from trend, scaled by 100. Foreign output measured as deviations from trend (series were logged before aggregated). Factor corresponds to the median of the simulated values and is multiplied by 10.

and real returns in Australia and the foreign block (figures 5.8 and 5.9). This point is further reinforced when looking at the plot of the inferred foreign factor together with the series for share prices (figure 5.12).[63] The main observation from that figure is that both share price series exhibit cofluctuations, particularly once again in 1987 and for most of the 1990s, which are also captured by the factor.

The significant influence of foreign share prices, specially during turbulent episodes in Australia, has been documented by Kortian and O'Reagan (1995) using simple rolling regressions of overnight share prices in Japan and the United States. Due to the simplicity of their framework, the authors cannot address if these linkages in international equity markets are associated with any real effects in Australia. On the other hand, Andersen and Subbaraman (1996), do not analyze the role of foreign shocks, but concentrate on the relation between share prices and investment. Based on simple regression equations, they find evidence that an increase in Tobin's Q -accounting for other determinants of capital formation- results in expansions in investment.

These findings are combined and highlighted with the dynamic factor framework.[64] Pin-

[63]Since the foreign share price index series are re-scaled to a base year and then aggregated, different scaling factors are needed to get a sense of the comovements in these variables.

[64]Real return series in this study coincide with measures of average Q in other papers advocating the role of innovations in foreign equity markets in Australian activity. Pagan and Dungy also find that changes in US Q (share prices to CPI) affect Australia's Q and output. They do not, however, disentangle the effects on an expenditure basis as here, and therefore do not emphasize the role of investment. Foreign influences in Australia

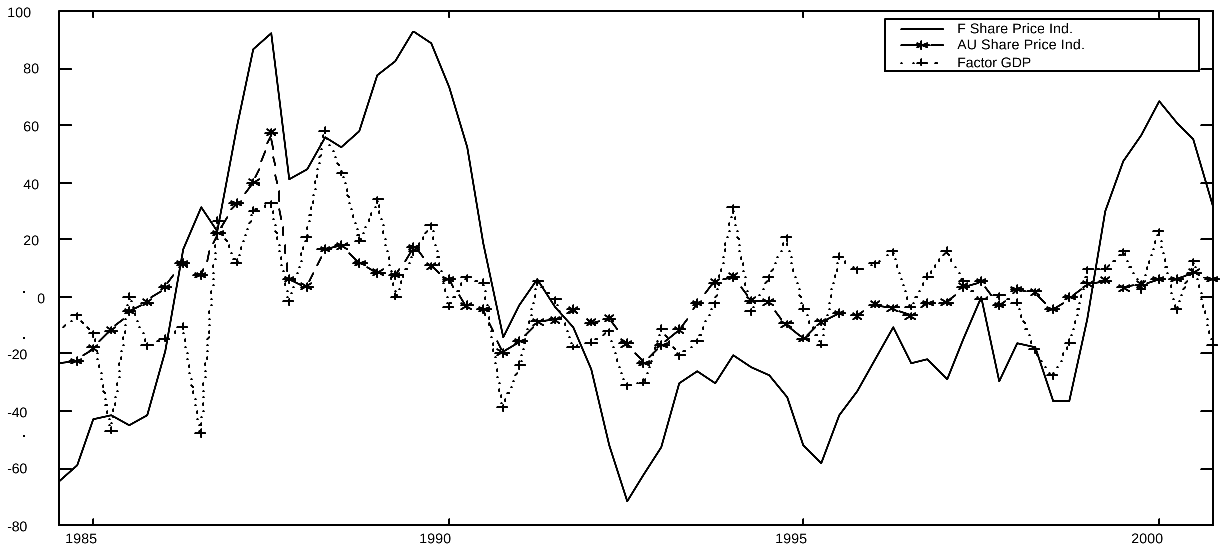

Figure 5.12: Foreign factor normalized with a contemporaneous expansion in foreign GDP, plotted together with foreign and Australian share prices, measured as log-deviation from trend, scaled by 100. Foreign share prices measured as deviations from trend (series were logged before aggregated). Factor corresponds to the median of the simulated values and is also multiplied by 100.

pointing the exact channels through which movements in foreign equity markets imply higher capital formation in Australia is a harder task. As already mentioned for Canada, higher equity prices would presumably decrease firms' cost of financing the acquisition of new capital. Foreign direct investment (FDI), and the increased availability of funds for subsidiaries of foreign companies in Australia, represents another potential mechanism of transmission for shocks originating in equity markets abroad. Another possibility, however, would be to emphasize how the performance of stock markets affects business confidence, which, in the anticipation of increased or decreased profitability, influences investment levels.[65]

To deepen our understanding of the first of these possibilities, FDI is included in the model. The response of FDI to the foreign factor proves to be fairly weak and, if anything, negative with a two quarter lag.[66] In regards to the expectations channel, two instruments are implemented to proxy for the expectations of future economic activity and the perceived state of the economy: unemployment expectations and consumer sentiment. Bearing in mind the caveats of using these instruments to proxy for expected profitability, it can be, nonetheless, observed in figure 5.9 that

through investment are also discussed in De Roos and Russell.

[65]See Preston and Debelle (1995).

[66]Unfortunately there does not seem to be further disaggregated data at the quarterly frequency on FDI for this country.

both series exhibit contemporaneous responses in the right direction (i.e. increased expectations of future activity and higher confidence) although the effect is short lived and reversed fairly rapidly.

Finally, just as for Canada, consumption also rises in response to the shock. Once again it is plausible, therefore, that innovations in foreign equity markets also affect private consumption through the effect on household net wealth.

Significantly, the factor methodology employed in the present study has allowed the consideration of a number of theories on the sources and propagation mechanisms of foreign shocks in Australia. As a result, the estimation of one *single* model has been enough to comprise and, more importantly relate findings scattered in a variety of papers published by the Reserve Bank of Australia, which have built on less sophisticated econometric methods. Therefore, factor models hold great promise because the simultaneous examination of a large number of series provides a broader view as opposed to the myopic perspective inherent to small econometric models.

5.3. Implications for the theory

Australia's experience suggests, both from the analysis of impulse responses and the calibration exercise, that exports might play a more muted rule in some countries than it is assumed in the NOEM literature. This observation highlights that assumptions on the sensitivity of exports to foreign conditions in small open economy models deserves further scrutiny. In particular, it may be wise to caution against frameworks which imply an excessive dependence on exports to account for the influence of external shocks.

Instead, this paper emphasizes that imports of capital goods and the concomitant increase in investment are the main transmission mechanisms for foreign disturbances in Australia, and an important channel for propagation in Canada. As a result, the treatment of imported goods in the NOEM may need to be revised. The model of McCallum and Nelson presents a promising direction by considering an alternative with imported intermediate goods. This study, nonetheless, stresses the need to push the analysis one step further, by incorporating explicit imports of capital goods in these economies.

The addition of investment and costs of adjustments in the analysis may also result in more realistic dynamics in these models, which could potentially better match the delays in response observed in the data. A couple of frameworks in the NOEM allow for the presence of capital goods, although these are not internationally mobile.[67] The IRBC literature on small open economies has, on the other hand, already set forth models, such as Kose (2000), which include traded capital and that may be a good starting point for the incorporation of nominal rigidities.

The synchronization of fluctuations in equity prices, with its concomitant fluctuations in investment, both in Canada and Australia, suggests that another worthy project in developing small open economy models is to consider the importance of foreign financing for domestic firms and to explore -both theoretically and empirically- any possible effects of asset prices on net worth, business confidence and other determinants of capital formation. Moreover, there is evidence that equity markets exert influence in small open economies also through the effects on household wealth. This last point further reinforces the need to account for the equity channel in the analysis.

To determine to what extent the fluctuations in the exchange rate are driven by shocks to equity markets is a final possible avenue for future research suggested by the results in this paper. A close link between commodity prices and exchange rates exists in these countries.[68] Therefore, if innovations to equity markets induce fluctuations in the exchange rate, and consequently in the terms of trade, they will also aid in explaining the transmission of shocks through imports in capital goods.

6. Conclusions

This paper proposes the application of dynamic factor methods for studying the sources and propagation mechanisms of foreign disturbances in two small open economies, Australia and Canada. The possibility of computing impulse responses in large datasets, which can then be used to provide a structural interpretation of the factors, represents one of the various advantages of the model of the present study, relative to previous work analyzing the influence of foreign shocks.

The analysis of a small open economy model, in vein of the New Open Economy Macroeconomics literature, serves to contrast the channels of transmission embedded in the theory with those highlighted by the estimated factors. For the case of Canada, the propagation mechanisms suggested by the theoretical framework, which highlights the role of exports, are evident. The present study also reveals, however, a role for interdependencies with the US arising from

[67] Uribe and Schmitt-Grohé (2000) and Chari, Kehoe and McGrattan (2000).
[68] Chen and Rogoff (2000).

commonalities in investment, synchronized equity markets and imports of capital goods. These last set of results are even more evident for Australia. Consequently, this analysis pinpoints one crucial potential shortcoming in the current state of the New Open Economy Macroeconomics literature: the omission of traded capital goods.

Both the application of factor models in international macroeconomics, as well as the observations made for the theory suggest new directions for research. From the theory point of view, the implications are clear. The dependence on foreign capital in these economies should be incorporated in the theoretical models.

Further work is needed, for instance, to understand exactly how foreign equity markets foster expansions in investment. This entails an additional exploration of the role of direct investment on businesses' expectations or the removal of liquidity constraints, to mention a few candidates. An interesting and related application of dynamic factors would be to examine how country interdependencies vary across monetary and exchange rate regimes. Developments in estimating models with time varying coefficients and volatilities also relying on Markov Chain Monte Carlo simulations, such as the work of Primiceri (2002), Sims and Zha (2002) and Aguilar and West (2000), offer interesting and promising extensions for the methods of this paper.

In the meantime, the results for Australia and Canada in this study call for a reconsideration of the current state of the literature on micro-founded sticky-price small open economy models. Ensuring that crucial assumptions in these models are in line with the data, seems an imperative task which is taken up here. If the ultimate objective is the development of a workhorse framework that will allow for a better understanding of country interdependencies and to analyze a range of policy issues for small open economies, then the conclusions of this paper will hopefully facilitate bringing theoretical efforts more in accordance with the actual characteristics of these countries.

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A. Appendix I:Dynamic Factor Model in Stacked Form

The model consisting of equations 2.4 and 2.5 can be written in stacked form, by stacking observations across series for a given time period, such that, considering any $1 \leq t \leq T$,

$$Y(t)_{[N\times 1]} = \begin{pmatrix} y^1(t) & y^2(t) & .. & y^N(t) \end{pmatrix}' \tag{A.1}$$

from where 2.4 becomes:

$$Y(t) = B\overline{F}(t) + \overline{\xi}(t) \tag{A.2}$$

the stacked matrix of factor loadings , $B = \begin{pmatrix} B_0 & B_1 & .. & B_p \end{pmatrix}$ is of dimension $N \times A$ with $A = K(P+1)$, while B_s at lag s, for $s = 1, ..., P$ is given by

$$B'_{s[N\times K]} = \begin{bmatrix} B_s^{1\prime} & B_s^{2\prime} & ... & B_s^{N\prime} \end{bmatrix}$$

where for any $i = 1, ..., N$

$$B^i_{s[1\times K]} = \begin{pmatrix} B_s^{i,1} & B_s^{i,2} & ... & B_s^{i,K} \end{pmatrix} \tag{A.3}$$

The vector of contemporaneous and lagged factors corresponds to:

$$\overline{F}_{[A\times 1]}(t)' = \begin{pmatrix} F(t)' & F(t-1)' & ... & F(t-P)' \end{pmatrix}$$

Equation (2.5), meanwhile, can be written in stacked form as

$$\overline{\xi}(t) = \Theta\overline{\xi}(t-1) + \overline{\eta}(t) \tag{A.4}$$

with

$$\begin{aligned} \overline{\xi}_{[Nx1]}(t) &= \begin{pmatrix} \xi^1(t) & \xi^2(t) & ... & \xi^N(t) \end{pmatrix}' \\ \Theta_{[N\times N]} &= diag(\begin{pmatrix} \phi^1(L) & \phi^2(L) & ... & \phi^N(L) \end{pmatrix} \\ \overline{\eta}_{[Nx1]}(t) &= \begin{pmatrix} \eta^1(t) & \eta^2(t) & ... & \eta^N(t) \end{pmatrix}' \end{aligned} \tag{A.5}$$

Assumption 1 implies a diagonal form for both the variance-covariance matrix of innovations to the idiosyncratic disturbances and the factors, respectively given by:

$$V(\overline{\eta}) = diag\begin{pmatrix} (\sigma_n^1)^2 & (\sigma_n^2)^2 & ... & (\sigma_n^N)^2 \end{pmatrix} = \Sigma_{\eta[N\times N]}$$

$$V(F) = diag(\begin{pmatrix} (\sigma_f^1)^2 & (\sigma_f^2)^2 & ... & (\sigma_f^K)^2 \end{pmatrix} = \Sigma_{F[K\times K]}$$

where σ_n^i and σ_f^j are the standard deviations of n^i for $i = 1, ..., N$ and f^j for $j = 1, .., K$, respectively.

The assumption of independence in the AR terms of the idiosyncratic disturbances implies further that the variance-covariance matrix of $\overline{\xi}$ is also block diagonal

$$V(\xi) = diag\begin{pmatrix} (\sigma_\xi^1)^2 & (\sigma_\xi^2)^2 & ... & (\sigma_\xi^N)^2 \end{pmatrix} = \Sigma_{\xi[N\times N]} \tag{A.6}$$

such that for all $i = 1, ..., N$:

$$(\sigma_\xi^i)^2 = (\sigma_n^i)^2/[1 - (\phi_1^i)^2 - (\phi_2^i)^2 - .. - (\phi_R^i)^2]$$

B. Appendix II: Data Sources and Transformations

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C. Appendix III: Factor Analysis in Canada.

This short appendix intends to supplement the presentation of the dynamic factor model in section 2 with the specifics of the analysis for Canada. The aim of this presentation is not to add any new insights but rather to provide the reader further details on the factor model estimated for Canada, in particular by making explicit the normalization and identification assumptions which parallel those in example 2.4.1. Therefore this exposition is mainly notational and included only for completeness. The model for Australia is composed of only three factors from where the discussion here is more general.

Equations (2.4) and (2.5) are estimated for Canada in a panel of 34 series. Details on the variables included are given in Appendix II.2.

The foreign block comprises sixteen variables, thirteen of which are US series, while the remaining three correspond to world prices (commodities, minerals and oil prices, with the last series abbreviated as $iolp$). US output, denoted gdp_{us}, is ordered first and the US share price index, sp_{us}, second, such that the stacked vector of foreign observations, at time t, is given by $Y_{for}(t)_{[16\times1]} = (gdp_{us}(t)\ sp_{us}(t)....oilp(t))'$, with the subscript $_{for}$ standing for *foreign*.

Similarly, the domestic block contains eighteen series for Canada, with labor productivity, lp_{cn}, and Canadian output, gdp_{cn}, ordered first and second respectively. The resulting vector of domestic series is therefore $Y_{cn}(t)_{[18\times1]} = (lp_{cn}(t)\quad gdp_{cn}(t)....)'$ (subscript $_{cn}$ for *Canada*) from where the stacked vector of observations is given by $Y(t)'_{[Nx1]} = [Y_{for}(t)'\ Y_{cn}(t)']$ ($N = N_{for} + N_{cn} = 34$).

Three lags are allowed for in the factor loadings (i.e. $P = 3$), which implies that the stacked matrix of loadings in equation (2.6) becomes

$$B_{[34\times16]} = \left[\begin{array}{cccc} B_{0[34\times4]} & B_{1[34\times4]} & B_{2[34\times4]} & B_{3[34\times4]} \end{array}\right] \tag{C.1}$$

As a result, equation (2.4), can be re-written, stacked by series, as

$$\left(\begin{array}{c} Y_{for}(t)' \\ Y_{cn}(t)' \end{array}\right) = B_{[34\times16]} \left(\begin{array}{c} F_{[4\times1]}(t) \\ F_{[4\times1]}(t-1) \\ F_{[4\times1]}(t-2) \\ F_{[4\times1]}(t-3) \end{array}\right)_{[16\times1]} + \left(\begin{array}{c} \xi^1(t) \\ \xi^2(t) \\ ... \\ \xi^{34}(t) \end{array}\right)_{[34\times1]} \tag{C.2}$$

with

$$F_{[4\times1]}(t) = \left(\begin{array}{cccc} f^1(t) & f^2(t) & f^3(t) & f^3(t) \end{array}\right)'$$

f^1 and f^2 foreign, while f^3 and f^4 domestic factors.

The idiosyncratic errors (ξ^i, $i = 1, .., 34$) in eq.(2.5), meanwhile, are assumed to follow AR(1) processes (i.e. $R = 1$).

As discussed, in section 2.4.1 identification assumptions for the dichotomy between domestic and foreign factors take the form of exclusion restrictions such that there is no feedback from the domestic factors into the foreign block. More explicitly, each of the matrix of factor loadings at lags s, given by B_s, which constitute B in equation (C.1), can be partitioned according to domestic and foreign series and factors, such that B_s , for any $s = 0, .., 3$, is given by:

$$B_s = \left[\begin{array}{cc} B^A_{s[16\times2]} & 0_{[16\times2]} \\ B^C_{s[18\times2]} & B^D_{s[18\times2]} \end{array}\right] \tag{C.3}$$

Identification assumptions are, just as in section 2.4.1, therefore, responsible for the zero sub-matrix in the upper right corner. Notice that the foreign block is ordered first and the domestic factors are placed second. Clearly, reversing this ordering would change the position of the submatrix of zeros without any implications for the analysis.

The normalization imposed in the matrix of contemporaneous loadings, B_0, following the partition in eq. (C.3), for $s = 0$, implies that $B^A_{0[16\times 2]}$ and $B^D_{0[18\times 2]}$ are lower triangular with ones on the main diagonal.

Taking into account this normalization and the identification assumptions, the first two rows of eq. (C.2) therefore entail expressing US output and share prices as:

$$\begin{pmatrix} gdp_{us}(t) \\ sp_{us}(t) \end{pmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ B_0^{sp_{us},1} & 1 & 0 & 0 \end{bmatrix} F(t) + ... + \begin{bmatrix} B_3^{gdp_{us},1} & B_3^{gdp_{us},2} & 0 & 0 \\ B_3^{sp_{us},1} & B_3^{sp_{us},2} & 0 & 0 \end{bmatrix} F(t-3) + \begin{pmatrix} \xi^{gdp_{us}}(t) \\ \xi^{sp_{us}}(t) \end{pmatrix}.$$

From here it should become clear that, as emphasized throughout the text, this particular normalization defines the first factor as representing all disturbances associated with both a contemporaneous expansion in US GDP (notice lagged responses are unrestricted and can take any sign) and cofluctuations with other series (including sp_{us}). The second factor, in turn, accounts for all additional underlying shocks associated with a contemporaneous increase in share prices and comovements with other variables, which do not result in any impact effects on US output (lagged cofluctuations between these two series are unrestricted).

D. Appendix IV: Estimation of the Phillips' Curve and the Taylor Rule

The estimation of the Phillips' curve (4.9)

$$\pi_t = \phi E_t[\pi_{t+1}] + (1 - \phi)(\pi_t) + \kappa(y_t - \widetilde{y}_t) \tag{D.1}$$

(output y, potential output $\widetilde{y}$, π inflation and $E_t[.]$ an expectation term based on information at time t) is inspired in the analysis by Gali and Gertler (2000).

Let $x_t = y_t - \widetilde{y}_t$ stand for the output gap. As discussed in Beechey et al. (op. cit.) unit labor costs are essential for explaining inflation dynamics in Australia, from where this series is used instead of the output gap. Moreover, using quarterly deviations of output from trend to proxy for the output gap results in estimates with the wrong sign (negative).

The estimation is done by GMM, with HAC standard errors obtained by a Barttlet Kernel (four lags). Despite the inclusion of an AR(1) term (ρ) to correct for serial correlation, the Q statistic (4 lags) and the correlogram suggests the presence of serial correlation in the residuals. This evidences some problems with this particular specification. No modifications have been introduced, nonetheless, except for the addition of a constant, to keep the equation as in the model.

The instrument list includes four lags of inflation, the log difference nominal exchange rate, unit labor costs, wages and a commodity price index in AU$. All series were downloaded from tables G and F in the *Bulletin Statistical Tables* published by the Reserve Bank of Australia (available online at www.rba.gov.au/Statistics).

GMM Estimates
Hybrid Phillip's Curve in Australia
Dependent variable: inflation π
1984:1 -2000:4

Variable	Coefficient	S.E. (HAC)
$\pi_{t+1\|t}$	0.54	0.01
π_{t-1}	0.54	0.01
x_t	0.015	0.002
ρ	-0.54	0.06
constant	1.64	0.25
Adjusted R2	0.97	
Q stat (value and p-value)	16.39	0.01
J-stat (p-value)	0.14	

Similar coefficients are obtained when using a four quarter moving average of log differences in CPI excluding "volatile items" (same data source as above, Table G1). However, in this case the coefficient on the gap jumps from 0.015 to 0.03. The results are not directly comparable given that this series is available only since 1990.

The Taylor Rule (equation (4.8) in text) parallels the long-run coefficients version of the specification in Orphanides (1998) such that

$$R_t = cons + (1-\rho_R)R_{t-1} + \theta_{gap}(y_t - \widetilde{y}_t) + \theta_\pi \pi_t + er_t \tag{D.2}$$

Orphanides dynamic specification with the short-run coefficients is given by

$$R_t = cons + (1-\rho_R)R_{t-1} + (1-\rho_R)[\widetilde{\theta}_{gap}(y_t - \widetilde{y}_t) + \widetilde{\theta_\pi \pi_t}] + er_t \tag{D.3}$$

clearly, the long run coefficients in (D.2) relate to the short run coefficients in (D.3) by

$$\theta_{gap} = \frac{\widetilde{\theta}_{gap}}{(1-\rho_R)} \quad and \quad \theta_\pi = \frac{\widetilde{\theta}_\pi}{(1-\rho_R)} \tag{D.4}$$

Note that this rule has no forward looking terms, as opposed to recent suggestions by some authors.

The interest rate corresponds to the quarterly average of the Cash Rate, and inflation is as above. Given ambiguities on how to best proxy for the output gap a simple strategy is adopted in this paper: to consider deviations from a quadratic trend. Using the HP filter to detrend the series results in output gap measures with seemingly implausibly large coefficients (sometimes well above 2)

Equation (D.3) is estimated by two stage non-linear least squares and the long run coefficient inferred as in (D.4). Standard errors for the long run coefficients are obtained by the delta-method. Once again, an AR(1) term, ρ, is allowed for in the errors to correct for serial correlation. In this case however, judging by the Q-stat the autoregressive specification is enough to remove the serial dependence in the disturbances. Finally the sample is as before, 1984:1-2000:4:

Two Stage Non-Linear Least Squares Estimates
Taylor Rule in Australia
Dependent variable: Cash Rate R
1984:1 -2000:4

Variable	Long Run Coefficients	S.E.
R_{t-1}	0.8	0.05
θ_{gap}	0.76	0.1
θ_{π}	1.13	0.13
constant	4.68	0.43
ρ	0.21	0.03
Adjusted R2	0.94	
Q-stat (value and p-value)	6.55	

The instrument list includes four lags of the interest rate, inflation and output gap plus the log difference of M3, the exchange rate and the terms of trade. Once again all series taken from *Bulletin Statistical Tables* published by the Reserve Bank of Australia and with the exception of M3 match those used to estimate the factor model and described in Appendix II. Results are insensitive to the use of the commodity price index or terms of trade as instruments. For the calibration, the coefficient on the output gap is scaled down by 4 to account for the fact that inflation and interest rates are measured as annual rates.

Insert Table 3 Here

Insert Table 4 Here

Insert Table5 Here

Table 6
Calibration
McCallum and Nelson's (2002) model for Australia
ρ AR(1) coefficients, σ standard deviations

Parameters	Values	Shocks	Values
ω_1	0.8	ρ_a	0.9
ω_3	0.17	ρ_v	0.2
ω_4	0.17	ρ_e	0
b_1	0.25	ρ_χ	0.3
ϕ	0.5	ρ_{y^*}	0.95
κ	0.015	ρ_{R^*}	0.88
ρ_R	0.76	ρ_{P^*}	0.8
θ_π	1.13	σ_a	0.008
θ_{gap}	0.8	σ_v	0.001
φ	0.075	σ_e	0.008
$\eta_{im,q}$	0.6	$\sigma\chi$	0.002
$\eta_{ex,q}$	0.7	σ_{y*}	0.008
η_{ex,y^*}	1	σ_{p^*}	0.001
		σ_{R^*}	0.008

Table 7: Standard Deviations

Series	Australian Data	Model
Output	1.96	1.31
Interest Rates	1.16	3.51
Consumption	1.47	1.62
Nominal Exchange Rate	4.34	7.27
Real Exchange Rate	4.3	7.47
Exports	3.38	5.17
Imports	6.04	3.66

Just as in the factor model, output, consumption, exports and imports are given in log deviations from a quadratic trend, while the interest rate (cash rate) is first differenced and the exchange rates log first differenced (see Appendix II). The sample is 1984:1-2000:4. As mentioned, the model matches fairly well the volatility of output and consumption. The parameters of the sensitivity of imports and exports to exchange rates and incomes, are similar to the values used in McCallum and Nelson (2001). Judging from alternative calibrations, which substantially alter these values, it seem that the main challenge is to match the volatilities of output, consumption, exports and imports with parameters that do not imply an excessive volatility of the exchange rate or interest rates.